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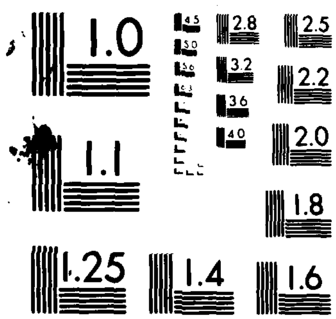

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DEPARTMENT OF THE AIR FORCE

AIR FORCE INSTITUTE OF TECHNOLOGY

AN INVESTIGATION OF TIME SERIES GROWTH CURVES AS A PREDICTOR OF DIMINISHING MANUFACTURING SOURCES OF ELECTRONIC COMPONENTS

Michael E. Brooks, Captain, USAF

LSSR 98-81

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Diminishing manufacturing sources (DMS) is a situation that occurs when the last manufacturing source discontinues or intends to discontinue production of items required to logistically support weapon systems throughout the Department of Defense (DOD). A practical method of forecasting DMS would enable DOD to anticipate and plan advance measures. The research postulated that a technology's life cycle curve could be re-expressed as a specialized time series growth curve known as the S-curve. Unit sales and dollar volume of sales were the two types of annual aggregate commercial sales data used to examine the growth curves of three families of obsolete electronic components. The component types were germanium transistors, germanium diodes/rectifiers, and receiving tubes. The research hypothesized that a standard nonlinear growth curve model could be fitted to each set of observed data using least squares nonlinear regression. The Pearl function appeared to offer the best mathematical explanation of the underlying economic nature of each time series growth curve in addition to providing the best overall data fit. Growth curve analysis indicated that DMS occurred at or near the saturation level of each curve; however, DMS did not occur at the same point on each curve.

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AN INVESTIGATION OF TIME SERIES GROWTH CURVES AS A PREDICTOR OF DIMINISHING MANUFACTURING SOURCES OF ELECTRONIC COMPONENTS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

Michael E. Brooks, BA
Captain, USAF

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has been accepted by the undersigned on behalf of the Faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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CHAPTER 1

INTRODUCTION

> It does not require an especially close look at the Air Force today to notice our great--and growing--dependence on electronics. As our forces have declined in numbers over the past decade, we have looked to electronics to help us redress the military balance through increased effectiveness of the forces we do have [26:97].

For several decades now, electronics has played a vitally important role in the military posture of the United States. As the preceding statement accurately indicates, electronics is a prime factor that has enabled the United States to seize and maintain a position of military superiority over potential adversaries.

However, this reliance on electronics is beginning to have some adverse effects on military readiness (9:1). Rapid technological advances in electronics accompanied by changes in the demand pattern of the nation's economy have created logistical support problems for many electronically operated weapon systems (55). Military equipment still uses a wide variety of older electronic components such as vacuum tubes and transistors while commercial demand for similiar items is virtually nonexistent. Demand for the newer microelectronic chip devices has forced manufacturers to discontinue production of the older products (12:20). The diminishing number of firms capable of manufacturing the older electronic components presents a serious situation in terms of economics and national security.

Diminishing manufacturing sources (DMS) is "the condition that occurs when the last manufacturing source ceases or intends to cease production of items needed in the DOD [Department of Defense] supply system [55:16]." In some literature, the acronym DMSMS (diminishing manufacturing sources and materiel shortages) is used to describe a more inclusive condition where a lack or shortage exists for any raw, in-process, or manufactured commodity of any kind (56:22). In this research report, both acronyms will be used synonymously to describe a situation in which the sole manufacturer of an electronic item states an intention to terminate production. The DMS problem exists in many DOD managed items, but it is "more noticeable and serious in electronic components due to the rapid technological advances taking place in the field [55:155]."

The DMS problem is an economic problem (7:2). Rapid technological advances during the past three decades have radically altered the structure of the electronics market. During this period, the developmental trend in electronic components was directed toward smaller, less expensive, and more reliable items (24:4). Additionally, these items generally realized higher operating speeds, wider applications, and consumed less power (26:101). Every generation of components is more advanced, increases market potential, and intensifies competition within the industry (38:30).

Similarly, the profit motives of the industry shifted in response to the ever increasing demand for the newer, more functional components. Sales of the older, less versatile items fell and many of the production lines closed accordingly. Furthermore, the concurrent development of the home entertainment, appliance, and computer industries spurred the demand for solid-state microelectronic devices, and the market structure changed dramatically within a 20-year period (38:29). During the 1950s, it is estimated that DOD consumed 90 percent of all parts produced (12:29). Today, DOD is only a ten percent user of these parts (12:29). Some estimates place consumption as low as seven percent (4:48). DOD lost its commanding position in the electronics market. This lack of influence compounds the problem of procuring the older vintage items because the volume required by DOD is insufficient to guarantee profits to the producers (4:48). As aptly stated by Brigadier General Patterson, a former commander of the Defense Electronics Supply Center (DESC),

> . . . the surge of electronics on a functional and economic scale during the past 30 years has outstripped standard linear growth patterns and reached exponential proportions. And the entrepreneural opportunities for firms, principally on the commercial market, have become extensive [38:30].

<u>Problem Statement</u>

DESC is the primary focal point within the Defense Logistics Agency (DLA) for DMS matters relating to electronic parts. On the average, DESC receives only a six-month notification of a manufacturer's intent to discontinue production (55:69). Six months proved to be insufficient time for DESC and its customers to appropriately respond to the actions required of the DMS situation (55:69).

A method to forecast the likelihood of a DMS situation would enhance DESC's operation and enable management to plan advance measures. Prior knowledge would also accomplish the following:

1. Allow DESC to perform a cost analysis of the available alternatives as cited in Appendix A. Presently, the life-of-type (LOT)[1] buy is the most frequently used option because it is expedient. Time does not permit DESC to explore the other alternatives in sufficient detail (55:p.11-11).

2. Enable DESC's customers to generate better estimates of the affected weapon systems and determine the number of parts required to logistically support the systems throughout their planned life cycles (55:71).

3. Minimize disruptions to normal operations.

4. Reduce the pressure caused by the time constraint.

---

[1]A life-of-type (LOT) buy is a one-time procurement of a sufficient quantity of an item to support the affected equipment or system until inventory phase-out (56:2).

Background

DESC is one of the six supply centers that comprise DLA. The mission of DESC is to provide "logistics management for assigned classes and items of electrical and electronic materiel [54:p.II-1]" that are used by the nation's military services and federal agencies. DESC presently buys, manages, and stores over 760,000 line items in 35 different federal supply classes for 22,000 military and civil agency customers (46). Logistics management in the form of procurement, inventory control, distribution, disposal, cataloging, and mobilization planning for electronic parts accounts for approximately five million requisitions annually and a quarter billion dollars in sales (46). Additionally, DESC is the item manager for the majority of the electronic parts used by the military services (47).

The Western Electric Company produced the first vacuum tubes used in military applications (12:5). The year was 1918 and the recipient was the U.S. Army Signal Corps (12:5). The vacuum tube was an absolutely essential component needed to develop future products such as the more advanced radios, television, and radar. Vacuum tubes come in a variety of categories which include receiving tubes, cathode ray tubes, power tubes, and the special purpose tubes used in radar, microwave equipment, and high power radios. Many tubes are still required for applications in radar scopes, computer terminals, radio and radar gear, and microwave communications equipment. However, the demand for low power receiving tubes is virtually nil in commercial applications since semiconductor devices such as the transistor began to functionally replace this tube (12:6).

In 1948, the Bell Telephone Laboratories announced the invention of the transistor (13:1). This small, low power, and more reliable device was functionally equivalent to the vacuum tube and could easily replace the tube on a one-for-one basis (12:9). However, the transistor's operating characteristics made it a more important device in computer applications. The simultaneous advent of the "stored-program digital computer provided a large potential market for the transistor [37:63]." Digital systems became practical because of the transistor, and the ideal combination of a new device and a new application provided growth stimulus for both (37:63).

It was not long before a new technological innovation would surpass the transistor. Research in the area of increased miniaturization progressed in the 1950s, and in 1958, Jack Kilby of Texas Instruments invented the silicon integrated circuit (13:1). Simply, "an integrated circuit is a group of inseparably connected circuit elements fabricated in place on and within [13:2]" a material called a substrate. The substrate is usually germanium or silicon. The integrated circuit is important in at least two respects. First, according to Meindl,

> The advent of microelectronic circuits has not, for the most part, changed the nature of the basic functional units: microelectronic

> devices are also made up of transistors, resistors, capacitors and similar components. The major difference is that all these elements and their interconnections are now fabricated on a single substrate in a single series of operations [28:70].

Second, the integrated circuit is a far more reliable device than circuitry using vacuum tubes or transistors (12:11). Integrated circuits contain significantly fewer wire connections--a large source of electronic failures. Additionally, integrated circuits consume less power and can withstand greater shock because the unit mass is so small (12:11).

Several evolutionary developments in the 1960s and 1970s have substantially increased the functional complexity and miniaturization of the integrated circuit. On the average, "the number of elements in advanced integrated circuits has been doubling every year [37:65]" since 1958. Steady technological advances in areas such as microprocessors and memory chips are rapidly making earlier integrated circuit designs obsolete (26). Market demand and decreased production costs are the driving forces behind the rapid evolution of integrated circuit demand (37).

DESC has been grappling with the technological evolution, or revolution as Noyce (37:63) puts it, in the form of the DMS problem. General Patterson stated that the first known DMS case occurred in the late 1960s when a major electronics manufacturer notified DESC that it would discontinue production of a particular vacuum tube type (38:29). The case was easily managed and there was no need for alarm. But as

General Patterson comments, the incident

> . . . was the tip of an iceberg. There were other companies, regular suppliers of tubes and other components to the Defense Department and its original equipment manufacturers, who were contemplating similiar moves further down the road . . . and on a more extensive scale [38:29].

The first major DMS case came in June 1970 when the Wagner Electric Company notified DESC that it was about to close the vacuum tube production line at its Bloomfield, New Jersey plant (9:1). A total of 44 tubes were involved, 23 of which Wagner was the sole source manufacturer (9:1). DESC had the option to purchase Wagner's remaining stock, and did so (38:29).

The largest DMS case involving vacuum tubes began January 15, 1976 when the RCA Corporation announced its intention to close the Harrison, New Jersey plant on July 30, 1976 (12:18). The plant manufactured receiving tubes, 110 of which RCA was the sole source (12:18). The reason for ceasing operation was "that the plant closing 'reflects the sharp decline in demand for receiving tubes in the face of the continuing shift to solid state devices in consumer, industrial and defense electronic systems' [12:18]."

High level concern for the diminishing sources of vacuum tubes began as early as May 8, 1973 when the Deputy Assistant Secretary of Defense for Production Engineering and Materiel Acquisition issued a memorandum requesting the military services and the Defense Supply Agency to "participate in an assessment of electronic equipment employing vacuum tubes [9:2]." Shortly thereafter, the DOD Ad Hoc Vacuum Tube Support Group (DVTSG) was formed to extensively evaluate the scope of the DMS problem and to recommend alternatives to the growing problem (9:2). The group's final report was released in June 1975, and it described a rapidly dying vacuum tube industry with the following symptoms:

> 1. Lost economy of scale for firms within the industry and for firms supplying the industry with materials.
>
> 2. Consolidation of operations and closures of unprofitable assembly lines were prevalent actions in order to cut costs.
>
> 3. Plans to close production lines were carefully guarded in order to avoid giving competitors an advantage in the market. Therefore, DOD would continue to receive little advance notice of discontinued products (12:19-20).

This report was significant because its description of the vacuum tube industry would become characteristic of future DMS situations for varieties of electronic components.

There were other efforts to identify and deal with the problem of diminishing sources. In 1974, the President established the National Commission on Supplies and Shortages (38:32). DOD responded by publishing DOD Directive 4005.16, Diminishing Manufacturing Sources and Material Shortages, on 3 December 1976 (58). DLA followed suit by releasing DLA Regulation 4005.6, Diminishing Manufacturing Sources and Material Shortages Program, on 25 May 1977 (56). Additionally, the Under Secretary of Defense for Research and Engineering tasked DESC in March 1977 to study the DMS problem as it pertains to electronic parts. The research took 18 months to complete and is the most professional, comprehensive, and informative study to date on the subject. Despite these actions, the annual number of DMS cases continues to grow at an exponential rate (47). Table 1 depicts the annual number of new DMS cases (31).

TABLE 1

ANNUAL DMS CASES*

FISCAL YEAR	NEW CASES
1976	2
1977	38
1978	41
1979	47
1980	82
**1981	93

*The term "case" refers to a situation in which a manufacturer informs DESC of a decision to terminate a production line. There can be numerous types of electronic components involved in a single case.

**As of 17 August 1981.

Transistors and integrated circuits became subject to DMS beginning in the mid 1970s. Motorola in 1975 phased-out its line of germanium transistors which were "used in field radios and the Univac computer employed in the Navy shipboard tactical data system [39:66]." DESC spent $2.8 million on a LOT buy in order to retain a sufficient quantity for future support of the affected weapons systems (39:66). Another major DMS case began June 16, 1978 when Motorola informed DESC of its plan to discontinue production of the Motorola

Emitter Coupled Logic II (MECL II) integrated circuit line in December 1979 (55:p.12-8). This decision affected logistics support of 16 major on-line weapon systems, one major system in the production phase, and numerous sales to foreign military customers (55:p.12-10). Final solution was to procure a LOT quantity of 652,714 items at a cost of $7.5 million (55:p.12-13). The most recent, and perhaps the largest and most complex, DMS case to date began in the Fall 1980 when the Signetics Corporation announced its plan to discontinue production of 4,000 integrated circuit parts (2). At least 800 of these were DESC managed items (2).

The life cycle of military equipment contributes additional complexity to the DMS problem. The acquisition process alone runs anywhere from 8-12 years for many weapon systems (55:78). However, "technology is improving so rapidly that the typical advanced component stays out front for less than five years," creating a distinct likelihood that there may be "an obsolescence problem by the end of the acquisition cycle [26:98]."

There is considerable industry contention that the DOD acquisition process inherently generates some of the DMS problems (24). For example, military preoccupation with performance and high reliability often creates standards for electronic components that are outside commercial mainstream technology (55:44). In essence, DOD stresses "performance and high reliability at the expense of supportability [55:44]." Furthermore, industry contends that "DOD purchases a much greater variety of types [electronic parts] than any individual company [55:44]." DOD could help minimize the severity of DMS in the operation and support (O&S) phase by using standard commercial parts (55:120).

Finally, military equipment is retained in the active inventory for as long as 20-30 years. This makes DMS virtually inevitable. For example, the F-106 and B-52 aircraft still use vacuum tubes in their radar systems while the Army is buying AN/VRC-12 combat radios that require germanium transistors (41:18). This problem is not unique to weapon systems. DOD has a tendency to use other equipment such as commercial grade communications gear "long after it has been retired from the commercial market and component manufacturers have stopped making spare parts [42:105]." Figure 1 illustrates the disparity between total and government requirements during the life cycle of a technology (38:31).

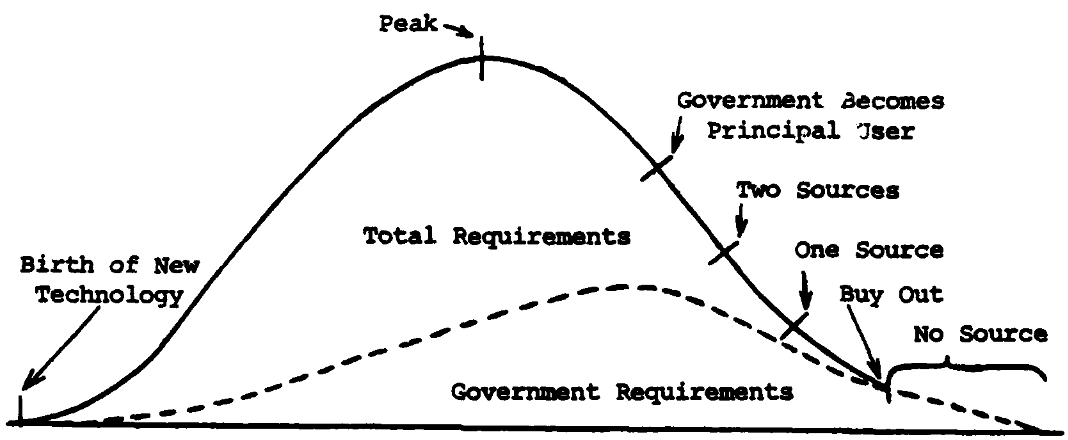

Fig. 1. Life Cycle of a Technology

It is important to note that once a production line closes, for all practical purposes, it cannot be reopened. Manufacturing conditions cannot be precisely duplicated because: (1) vital skills and know-how are lost over time, (2) the follow-on manufacturing process would never be precisely the same as the preceeding process, and (3) technical specifications never precisely define a manufacturing process (12:23). Additionally, the cost to resume production would be enormous (12:24-25).

Economics is the bottom line of the DMS problem. Technological change in the electronics industry is faster than in any other field (12:1). From industry's perspective, the incentive is "to maximize returns by creating whole new markets through infusions of new technology, concentrating on the consumer markets [12:25]." New advances bring improved performances that have great potentials for wider applications and increased market share (34). Production of older items becomes unprofitable as demand for the newer items increases. The DOD problem is that, as a user of seven percent of the market's products, it cannot influence or direct mainstream technology as it once did in the 1950s and early 1960s (4:48-49). Additionally, production lines will not remain open for such a limited demand.

The DMS problem for DESC is also economic. Appendix A lists DESC's alternatives when confronted with a DMS case. However, in a majority of the DMS cases, DESC initiates a LOT purchase because time prohibits extensive research and cost analysis of the other options (55:p.11-11). Funds for LOT purchases originate in DESC's revolving stock fund, and replenishment of the fund can only come through annual sales to DESC's customers (38:29). Table 2 depicts the annual expenditures for DMS buy-outs (5:8;19).

TABLE 2

DMS LOT BUY EXPENDITURES

FISCAL YEAR	DOLLAR AMOUNT (MILLIONS)
1974	$ 2.0
1975	4.7
1976	10.0
1977	10.3
1978	9.4
1979	11.7
1980	28.4
*1981	40.0
*1982	52.0
*1983	64.0

*FY 1981, FY 1982, and FY 1983 are estimates as of 17 August 1981.

When DESC receives notification that a manufacturer intends to cease production of some components, DESC will usually have six months to decide a course of action (55:69). DESC immediately notifies its customers of the situation and requests their LOT requirements for the items. Basically, two major problems arise at this point. First, six months is generally insufficient time to thoroughly explore all the alternatives (55:69). Secondly, the customers encounter a tremendous difficulty in determining three pieces of essential information: (1) the number of systems supported by the components, (2) the number of components required to support a system, and (3) phase out date of the affected system(s) (55:p.11-11). In most cases, DESC's customers have to manually extract the information because automated systems are nonexistent (55:72). Therefore, customer response can be grossly inaccurate or unavailable within the six-month time criterion.

DESC policy on LOT purchases is to buy a ten-year supply of the DMS items. The buy-out quantity is computed by determining the demand placed on DESC for the preceding 24-month period and multiplying the amount by a factor of five to arrive at a ten-year order quantity. This is standard operating procedure unless the user informs DESC otherwise. Foreign Military Sales requirements are not loaded into the final buy-out quantity unless DESC receives funded requisitions (2).

There are three major disadvantages in performing LOT buys (7:9). First, a straight line approach for determining the optimal order quantity is "both arbitrary and risky [55:p.11-13]" because such a policy can easily lead to over- or underbuying (55:p.11-13). A survey performed of LOT buys for fiscal years 1974 to 1978 indicates that this may indeed be the case (55:p.11-14). The second disadvantage is that the penalty for underbuying could have adverse consequences. A shortage of components could result in a threat to national security and become an economic catastrophe. Third, storage costs for LOT buys can become high. For example, the 652,714 integrated circuits purchased during the MECL II DMS case had to be stored in pressurized, nitrogen-filled cannisters (55:p.12-14).

Research Objective

Three trends appear likely to continue in the immediate future. First, technological advancement in the electronics field will continue at an increasingly rapid pace, which will in turn accelerate the rate at which older technology components become obsolete. Second, the number of DMS cases will continue to grow annually. Third, most manufacturers, for proprietary reasons, will provide DESC with short advance notice of their intentions to terminate production lines. Therefore, the objective of this research is to develop a practical method of forecasting a DMS situation.

Two specific objectives of this research are as follows:

1. To determine if a time series of aggregate annual commercial sales data can satisfactorily explain the life cycle growth of certain families of obsolete electronic components. An attempt will be made to see if the data sets form "S-shaped" growth curves as described in the techno-

logical forecasting literature, and then to find mathematical equations that best explain the actual curves.

2. To determine the feasibility of using the S-curve as a predictor of DMS, provided the data sets for the obsolete components form S-curves. The curves will be examined to see where DMS occurred in the life cycle growth of the obsolete components.

Research Assumptions

The data used in this research are aggregate annual sales volume and dollar volume of sales for three families of electronic components: (1) receiving tubes, (2) germanium transistors, and (3) germanium diodes/rectifiers. The data came from the Electronic Industries Association's (EIA) Electronic Industries Year Book 1969 and the 1979 Electronic Market Data Book. EIA is a trade association with a membership that contains most of the nation's electronic manufacturers (11:ii). It will be assumed that the EIA data accurately reflects the total U.S. factory sales for the above mentioned families of electronic components.

CHAPTER 2

LITERATURE REVIEW

This literature review examined the evolution of electronic component technology and explored the various techniques used in technological forecasting. There were three reasons for this review. First, some knowledge of past electronic developments was necessary to understand the present and predict the future. Second, technological forecasting presents one possibility for minimizing the severity of future DMS cases (55:5). Additional information in this area was necessary to develop the research methodology. Third, a knowledge of both areas helped to refine research objectives, hypothesis, and methodology.

Evolution in Electronic Component Technology

There are functionally two broad types of electronic components--active and passive. Active components such as vacuum tubes and transistors can amplify, modulate, or generate current (28:70). They are the "building blocks" of electronic circuits (12:3). Passive components such as resistors, capacitors, and inductors store current or impede its flow but do not add to it. Further discussion will be limited mainly to active components because they are more vulnerable to the accelerated pace of technological innovation (55:26). Hence, active components are more susceptible to the DMS problem than passive components (55:26).

The vacuum tube first appeared near the beginning of the 20th century. Its invention was significant because the vacuum tube, in conjunction with other active and passive components, enabled scientists and engineers to develop and expand electronic principles such as amplification and modulation. Many vacuum tubes still are produced today. Some basic varieties include receiving tubes, cathode ray tubes, high power tubes, and microwave tubes (11:92). Only the receiving tube has shown a decline in sales over the past 25 years, which can be attributed to the introduction of the transistor and integrated circuit (11:87). The other tube types still show increasing annual sales because more advanced technologies have not been developed to replace them (11:92). In general, a vacuum tube is nothing more than a series of metal plates, grids, and filaments encased in a glass or metal container. The elementary operating principle is the controlled flow of electrons from the negative to the positive plate.

The invention of the transistor in 1948 was not as important as the technology it represented. The new technology became known as semiconductor or solid-state technology, and it involved the manipulation of the physical and chemical properties of a material or substrate known as the semiconductor (28:72). A semiconductor is a material, usually germanium or silicon, with properties of both a conductor and an insulator (17:94). These properties can be deliberately altered through a process called "doping" (28:72). This involves the introduction of impurities such as phosphorous or boron into the crystal structure of the semiconductor in order to achieve some desired electrical effects (28:72-73). Integrated circuitry or microelectronics is a more advanced technology that involves similar manipulations of the physical and chemical properties of materials (28).

The term "semiconductor" has several meanings. First, it could mean simply the substrate material as mentioned in the preceeding paragraph. Second, in a broad sense, it could refer to the nature of the technology and its manufacturing process. This definition would incorporate all components having semiconductor materials including integrated circuits. Third, the term could mean only discrete[1] components containing semiconductor material such as transistors and diodes. In this report, a semiconductor will be a discrete device. Integrated circuits will be referred to as a separate technology.

Early in solid-state history, a fundamental transition began in the use of substrate materials. Originally, germanium was the material commonly used in making semiconductors because it was relatively simple to process (57:105). Silicon eventually became the primary substrate for three

[1]A discrete semiconductor is a "device containing only one active device, such as a transistor or a diode [17:92]." Appendix B contains definitions of some electronic terms used in this report.

reasons. First, it was more abundant and cheaper than germanium (57:105). Second, silicon components can operate at higher temperatures (57:105). Third, and more important, the physical and chemical properties of silicon make it a more attractive compound than germanium (57:105). The market position of silicon discrete components still remains strong today; however, germanium components are obsolete for all practical purposes (11:103).

The presence of transistors did not immediately affect the production rates of receiving tubes nor did it "significantly alter the established component industry structure [57:11]." As transistor cost declined and as their greater reliability and endurance became apparent (28:79), they began to replace receiving tubes on a one-for-one basis (55:80). However, "the introduction and widespread use of integrated circuits . . . in the 1960s brought important changes to . . . [the component industry] structure [57:11]." The fact that several circuit functions could be performed by one integrated circuit chip made it a more suitable replacement for receiving tubes, transistors, and many passive components (57:11). As Skinner and Rogers state:

> The large-scale integration of integrated circuits beginning in the early 1960s has been perhaps the most striking feature of modern electronics. . . . the switch from discrete component circuits to integrated circuits bears little similarity to the conversion from vacuum tubes to transistors and in fact is more dramatic. In the later case, a new circuit design based on solid-state technology had to be developed, but the components remained observable

> throughout the circuit design process. However, with integrated circuits the entire circuit design function and the priorities that used to be associated with it are substantially altered [44:38-39].

There are many different classifications of integrated circuits. This report will consider four broad types: (1) linear, (2) digital, (3) microprocessors, and (4) microelectronic memory devices. Linear, or analog, integrated circuits operate in a non-digital manner. For example, voltage values for linear integrated circuits can be any value within the component's operating limits (17:91). These components are typically used in radar sets and guidance systems (44:40).

An important product of integrated circuit technology has been the development and advancement of the digital logic circuit. Digital integrated circuits operate "with signals that have only two recognizable levels" such as a high voltage and a low voltage [28:78]. These components find their largest application in computers (44:40).

One apparent trend in this type of integrated circuit has been the evolution of the bipolar digital logic circuit. The first family of bipolar circuits was introduced in the mid-1950s and was called transistor-resistor logic (TRL) (28:78). "The circuits were assembled entirely from discrete components and the number of resistors was maximized because resistors were the cheapest and most reliable devices" at the time [28:79]. Diode-transistor logic (DTL) appeared in the late 1950s and early 1960s when semiconductor diodes "became cheap enough to compete with resistors [28:79]."

DTL circuits began to functionally replace TRL circuits just when the next generation of logic designs known as resistor-transistor logic (RTL) appeared in the early and mid-1960s (28:79). RTL was the first integrated circuit version of the bipolar digital logic circuits, and it too began to functionally replace its TRL and DTL predecessors. Still a fourth major logic family was introduced and "remains today the commonest form of bipolar technology [28:79]." Known as transistor-transistor logic (TTL), it has numerous technical improvements over earlier versions (28:79). However, with the exception of the TRL circuit, "newly introduced logic families have not completely displaced older ones; rather, each of the families has found applications for which it is best suited [28:79]."

The third major classification of integrated circuits is the microprocessors. The microprocessor appeared in 1971 and as Toong defines:

> A microprocessor is the central arithmetic and logic unit of a computer, together with its associated circuitry, scaled down so that it fits on a single silicon chip (sometimes several chips) holding tens of thousands of transistors, resistors and similar circuit elements . . . . As in the central processing unit, or CPU, of a larger computer, the task of the microprocessor is to receive data in the form of strings of binary digits (0s and 1s), to store the data for later processing, to perform arithmetic and logic operations on the data in accordance with previously stored instructions and to deliver the results to the user [49:146].

Microprocessor development was part of "the microchip revolution" of the 1970s [48:97]. The microprocessor affords low-cost computing power, and is being used in numerous applications where computing was once considered too costly or computer control was unthinkable (49:151). It is undergoing a very rapid evolutionary development. Sepcifically, the progression of microprocessor generations in the 1971 to 1981 time frame has been 4-bits per chip, 8-bits, 16-bits, and now 32-bits per microprocessor chip (40:83).[2] Microprocessors have been replacing predecessor circuits in a fashion similar to a "multilevel substitution process;" that is, one microprocessor type replaces an older type while at the same time being replaced by a newer type (43:89).

The fourth classification of integrated circuits is the microelectronic memory. This integrated circuit has the capacity to store bits of data, and has demonstrated versatility and a high degree of compatibility with many other electronic devices (16:131). "The most widely used form of electronic memory is the random access read/write memory . . . chip" which is capable of storing as many as 64,000 (64K) bits "in an area less than half a centimeter on a side [16:135]." Each bit is held in a single transistor storage cell. The memory was first introduced in 1972, and like the microprocessor, has undergone an equally rapid evoluti[illegible]. Between 1972 and 1980, the progression of generations has been

[2]A bit is a binary digit (0 or 1).

1,000 (1K) memory cells per chip, 4,000 (4K) memory cells, 16,000 (16K) memory cells, and 64,000 (64K) memory cells per chip. The multilevel substitution phenomenon is similarly apparent among the microelectronic memory devices.

The preceding synopsis was a broad overview of the more important developments over the past three decades. It did not cover the complete spectrum of electronic developments.

One area, however, cannot be overlooked. The discrete transistors, and those transistors used in the digital logic circuits previously mentioned, were of a basic class known as bipolar or junction transistors. They were the early transistor versions and were called bipolar "because charge carriers of both polarities are involved in their operation [28:74]." A second class of transistors appeared in the early 1960s, and is called the field-effect or unipolar transistor. "Of the several types that have been devised, the one that is common in microelectronics is the metal-oxide-semiconductor [MOS] field-effect transistor [28:74]." In MOS devices, "only one kind of charge carrier is active in a single device [28:76]." MOS technology was an improvement over bipolar technology because it enabled more circuit elements to be packed on a single silicon chip (28:76). The development of microprocessors and microelectronic memories became easier because of MOS technology.

MOS technology has undergone some evolution itself. CMOS, NMOS, AND PMOS are a few of the different MOS varieties appearing in the last 20 years. Each has different operating characteristics, but one large trend has been the one-for-one replacement of PMOS by NMOS devices because the latter operates faster with reduced power consumption (28:81).

In summary, the following comments can be made concerning the evolution in electronic component technology.

1. "Semiconductor technology, although often referred to as a homogeneous unit, is in reality a number of technologies [19:27]."

2. Newly introduced components are generally smaller and more complex. New components often perform specialized functions that previously required a larger component or large numbers of components. Examples are digital logic chips and microprocessors.

3. A direct one-for-one *functional* replacement of electronic components occurs on a limited scale and almost solely within an established type of technology. Multilevel technological substitution within some component families occurs because of the accelerated pace of new developments. Microprocessors and microelectronic memories are examples of multilevel substitution.

4. All electronic components have one universal trait. Specifically, each family of components can be identified with a distinct technology. Therefore, the life cycle of the component family will coincide with the technology's life cycle. It is quite common for manufacturers to take a life cycle view of their products (55:p.12-9).

Technological Forecasting

Interest in technological forecasting is fairly new. The bulk of current literature was written in the late 1960s and early 1970s, and can be attributed to "the influence of technological advance . . . in many sectors of national activity [20:11]."

There is no universally accepted definition of technological forecasting because "various researchers see different meanings at different levels of planning [22:1]." However, the following definition offered by Martino is acceptable: "A technological forecast is a prediction of the future characteristics of useful machines, procedures or techniques [27:2]."

The value of technological forecasting lies not in the forecast it can render, but as a tool that can assist the manager in the decision making process. Forecasting can be particularly useful as a prerequisite for planning (18:19). However, forecasting is not a substitute for planning or decision making. As Jabery aptly states

> Technological forecasting is not a panacea; it describes not what the future will be but only what the future could be. It does not take away any of management's decision making power; it merely helps those who make decisions to assess the consequences more adequately [18:10].

Technological forecasting does not, nor should it be expected to, provide completely accurage and perfect information about the future (22:9). "To be worthwhile the forecast must simply allow a better operation than could be achieved without it [22:9]."

Technological forecasting techniques fall in two broad categories: normative and exploratory. Normative technological forecasting seeks to identify future requirements in order to determine the rate of technological progress needed to meet those requirements (20:15). "The objective is to determine the technological capability which will be required to carry out some function, based on some estimated or projected demand [27:287]." Exploratory forecasting, on the other hand, seeks to identify key performance parameters in order to predict future progress by extrapolating existing rates of change in the parameters (27:287).

The life cycle of a technology is an important concept to understand before exploring various technological forecasting techniques. The presence of a technology is a response to a need or demand; it does not simply appear, nor is it here forever (22:10). The life cycle of a product, or the technology it represents, follows a predictable growth pattern as described in the various stages of the life cycle curve shown in Figure 2 (55:79).

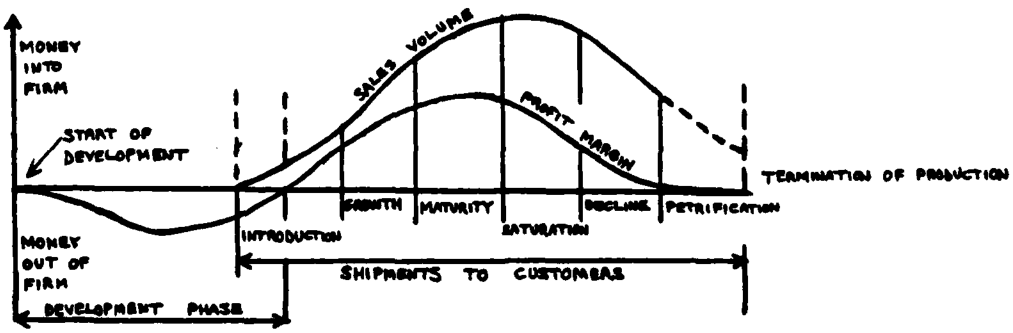

Fig. 2. Product Life Cycle

The introduction stage marks the commercial appearance of a product. Sales rise slowly in this stage. The growth stage is characterized by an accelerated sales rate. Sales begin to stabilize and then decelerate in the maturity and saturation stages. This will probably occur because of the competition created by other products. Eventually sales will decline to a point that it will become economically impractical for a manufacturer to continue production. Specific knowledge regarding a product's life cycle position can be a very valuable piece of information for the manager.

There are numerous quantitative and qualitative techniques used in technological forecasting. J. R. Bright, author of several texts and numerous articles on technological forecasting, conveniently classifies these techniques in five categories according to their concepts: intuitive forecasting, normative or goal-oriented forecasting, dynamic modeling, monitoring, and trend extrapolation (3:p.3-6).

"Intuitive forecasting is a systematic assessment of informed opinion [3:p.3-6]." This is a qualitative approach and is generally used when data are scarce or nonexistent. The objective of intuitive forecasting is "to bring together in a logical, unbiased, and systematic way all information and judgments which relate to the factors being estimated [6:49]." Intuitive forecasting is particularily appropriate in future-oriented thinking such as predicting new technological developments (6:49).

Perhaps the most popular intuitive method is the Delphi technique. In this technique, expert opinion is solicited through polling. Three conditions are essential: (1) anonimity, (2) statistical display, and (3) feedback of reasoning (3:p.5-1). Opinion is solicited through questionnaire, and feedback contains the opinions of other experts in addition to statistical displays reflecting data on the answers to previous questions (3:p.5-1). The objective is to proceed through several iterations in order to achieve consensus opinion (3:p.5-2).

"Normative or goal-oriented forecasting assumes that technology will materialize to fill needs [3:p.3-7]." Several techniques fall in this category of forecasting, and each involves some form of structured analysis in examining future needs. "Methodology in this approach ranges from nothing but a protagonist's view of the future . . . to highly structured reasoning procedures [3:p.7-1]."

The third category of forecasting techniques is dynamic modeling. Basically, dynamic modeling involves the design of a model that hopefully incorporates appropriate variables that express a valid relationship of the situational interactions (3:p.9-1). Simulation is then used to obtain a forecast. Dynamic models have great potential for defining complex systems; however, scrutiny is a prerequisite in using them. For example, assumptions must be valid, the model must express the correct variables and coefficient values, and data must be carefully selected (3:p.9-1).

Monitoring is the fourth category and involves assessing the significance of new and potentially significant technological events. Monitoring, as Bright explains,

> . . . is an attempt to identify technology in its embryo stages, as well as recognizing signals that will influence its direction, then following the appropriate phenomena in order to determine the rate of progress and the true character of the impact [3:p.3-7].

Effective monitoring is an active process that involves continuous evaluation and review.

Trend extrapolation is the final category. The techniques in this category vary in quantitative sophistication, and are frequently used in technological forecasting when historic data are available. Trend extrapolation rests on the assumption that the factors influencing the historic data in the past are likely to continue in the future (22:32). That is, the influencing factors have a tendency to remain fairly constant over time and will tend to exhibit "patterns of behavior that form a fairly well-behaved trend [3:p.6-1]." The influencing factors are usually defined in terms of some technical parameters or attributes (22:32). Therefore, one could use these parameters and the appropriate data to develop a past time series, and extend it beyond the present to predict a future situation or determine the rate of change in technological development (3:p.6-1).

Trend extrapolation techniques have produced some interesting, useful, and promising results. Two important conclusions can be developed from trend extrapolation studies.

First, Martino (1972), Bright (1972), Lenz (1962), and Mohn (1972) cite numerous situations in which these techniques were used to analyze technological progress in various fields such as aircraft speeds, automotive horsepower developments, computer advancements, and typesetting technology. They demonstrated the forecasting possibilities of trend extrapolation provided the availability of: (1) a knowledge of the key technical parameters, and (2) a time series of data. A forecast is developed by projecting the extrapolated time series into the future.

Second, trend extrapolation demonstrates that "technological progress does not occur in a random fashion [21:181]." This was a recurrent conclusion in the aforementioned studies of technological progress. A frequently used model in trend extrapolation is the growth curve, or more commonly called, the S-curve (59:107). The S-curve had its origin in biological and demographic studies by researchers such a Pearl and Gompertz (27:111-115). However, in the search to develop forecasting methods, researchers noticed "a similarity between the behavior of biological growth and the growth in performance of technological devices [27:103]." Studies indicate that when long-term technical data are plotted against time, an S-curve will appear which reflects a slow start, rapid growth, and a leveling off against some natural or man-made limit (3:p.6-1). The leveling off of one technology indicates that time is ripe for a succeeding technology (29:252). The new technology is called the envelope curve (29:233).

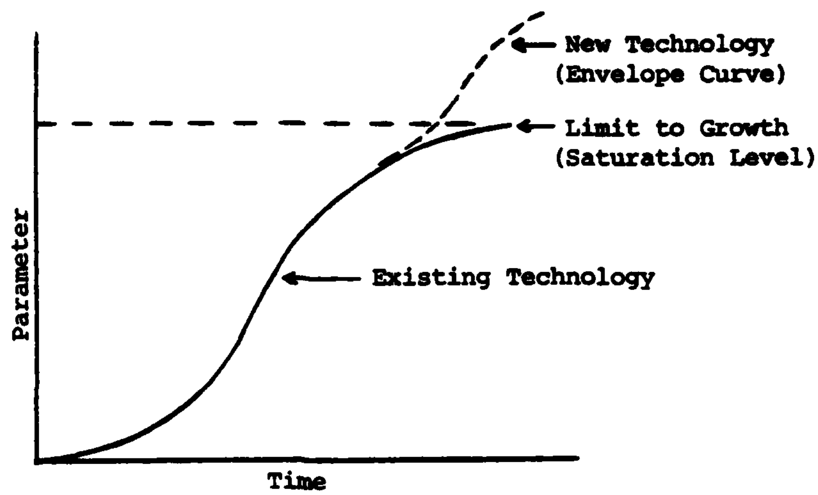

Fig. 3. The S-Curve

Trend extrapolation, particularly the S-curve, has important implications for analyzing the DMS problem. The reasons are as follows:

1. "The S-curve is . . . fundamental since it gives expression to the fact that all technologies are finite [21:189]."

2. Trend extrapolation is an exploratory, fairly simple, and objective approach to forecasting. Results are objectively reproducible.

3. The S-curve and the life cycle curve are analogous expressions for growth patterns. Both express the same relationship in product or technology growth; i.e., growth is characterized by a slow start, rapid growth, and termination after some period of time. Therefore, trend extrapolation in the form of an S-curve can be used to graphically and

mathematically develop the life cycle curve for a family of electronic components. The DMS phenomenon can be studied given the proposition that the life cycle for a family of electronic components represents the life cycle of its respective technology.

Research Hypothesis

This research will test the hypothesis that, given the annual commercial sales data indicate a life cycle curve, this relationship can be re-expressed in the form of an S-curve for which a standard growth curve model can be fitted to the observed data using the least squares method of regression and a five percent or less value for the coefficient of variation.

Research Question

The level of aggregate consumer demand will dictate when DMS will occur for a particular technology. The question posed by this research is the following: At what point in the technology life cycle does dwindling demand halt production? That is, where on the technology life cycle growth curve does DMS occur?

Based upon a broad knowledge of the DMS phenomenon and the life cycle of a technology, reasonable intuition could lead to the speculation that DMS occurs at or near the saturation level on the growth curve, and that DMS occurs at the same point regardless of technology. The research question can therefore be subdivided as follows:

1. Does DMS occur at or near the saturation level on the growth curve?

2. Does DMS occur at the same point regardless of the technology?

The answers to these questions are important because they can contribute to the ability to forecast DMS. If DMS consistently occurs at the same point, the task of predicting a DMS situation is greatly simplified. Therefore, this research will determine, for each of the sample technologies, the point at which DMS occurs on each S-curve and whether these points coincide.

CHAPTER 3

METHODOLOGY

Chapter 1 stated two specific objectives of this research. The first objective is to determine if a time series of aggregate annual commercial sales data can satisfactorily explain the life cycle growth of certain families of obsolete electronic components. The second objective is to determine the feasibility of using the S-curve as a predictor of DMS provided the data sets for the obsolete components form S-curves. This chapter specifies the procedures for accomplishing these objectives.

Data Search

The purpose of the data search was to collect aggregate annual commercial sales data on families of electronic components that have already, or will soon become, obsolete. The annual number of sales and/or the dollar volume of sales were the data specifically sought throughout the search. The criteria for determining the acceptability of the data were as follows:

1. The data were sufficient to form a consecutive time series representing a fairly complete life cycle for each component family.

2. The data reflected growth in the overall U.S. market. This is a primary concern of DESC because: (1) U.S. manufacturers constitute most of DESC's suppliers, and (2) government regulations prohibit a foreign manufacturer from becoming a sole source supplier (55:145; 58:3).

Annual sales volume and dollar volume of sales for receiving tubes, germanium transistors, and germanium diodes were found early in the search. Therefore, the remainder of the search concentrated on locating data for the earlier versions of integrated circuits. Integrated circuits of particular interest were the following:

1. TRL, RTL, and DTL families of bipolar digital logic circuits.

2. 1K NMOS memory devices.

3. 4-bit MOS microprocessors.

The techniques of collection included four approaches: a literature search, letter correspondence, telephone contacts, and personal visits. Data were sought from the following sources:

1. Various electronic journals and periodicals.

2. Industry trade associations.

3. Federal document collections at two universities in the Dayton, Ohio area.

4. Numerous military organizations with missions that support electronic weapon systems.

5. Several agencies of the Federal government.

6. Several manufacturers.

7. Independent research firms.

Appendix C contains a detailed listing of the sources and methods of contact.

Data Adjustment

The problem with using dollar volume of sales data is that, over time, the purchasing power of the dollar changes value. Therefore, dollar sales values were adjusted to constant 1967 dollars in order to compensate for the economy's inflationary and deflationary fluctuations.

Producer Price Index (PPI)[1] statistics, published by the U.S. Bureau of the Census, were selected to restate dollar sales values in uniform dollars of purchasing power. The U.S. Bureau of Labor Statistics constructs PPI statistics "to measure average changes in prices of all commodities, at all stages of processing, produced or imported for sale in primary markets in the U.S. [53:473]." The PPI is "based on approximately 2,800 commodity price series [53:473]," and the indexes are computed so that index changes reflect price changes rather than quantity changes (30:107-108).

Analysis of the Research Hypothesis

As stated in Chapter 2, this research hypothesizes that provided the annual commercial sales data indicate a life

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[1]Prior to 1978, the Producer Price Index was known as the Wholesale Price Index (53:473).

cycle curve, this relationship can be re-expressed in the form of an S-curve for which a standard nonlinear growth curve model can be fitted to the data sets using the least squares method of regression. A visual inspection of the data sets indicates general life cycle development; that is, every data set shows a period of growth in annual sales to some peak year which is followed by a period of declining sales (55:78).

The general problem of finding equations which fit given sets of data is called curve fitting. There are several alternative mathematical functions that explain various types of nonlinear time series trends. However, the problem in curve fitting becomes one of choosing the function that best describes the underlying economic nature of the time series in addition to providing the best fit. Some knowledge of the time series' characteristics is necessary before selecting eligible nonlinear equations.

A logical first step is to manually graph each data set. By definition, a time series is a collection of data that expresses a relationship between two variables where the independent variable is time (15:439). The Y-axis measures cumulative sales data, either annual sales volume or dollar volume of sales, while the X-axis measures time. The basic shape and underlying nature of the time series should become apparent at this point.

It will be assumed at this point that each data set produces an S-curve. Several equations are available that mathematically describe the pattern of S-shaped growth curves.

A common formula for producing an S-curve is the Pearl curve. Also known as the Pearl-Reed formula or the logistic curve, the equation is stated as

$$y = \frac{L}{1 + ae^{-bx}}$$

where L is an upper limit to the growth of the y-variable, a and b are parameter values, e is the base of the natural logarithm (2.71828), and x is time (27:111-113). The Pearl curve is often expressed in general terms as $y = 1/(a + bc^x)$, where a, b, and c are parameter values and x is time.

Another frequently used growth curve is the Gompertz curve (27:113-115). The equation for the Gompertz is

$$y = Le^{-be^{-kx}}$$

where L is an upper limit to the growth of the y-variable, b and k are parameter values, e is the base of the natural logarithm, and x is time. It is common for the Gompertz curve to be expressed in general terms as $y = ab^{c^x}$ where a, b, and c are parameter values and x is time.

The implicit assumption in using the Pearl or the Gompertz model is that there exists an upper asymptote or limit to activity growth, and that this limit is determined from historic data (33:657). Both models describe two types of growth patterns. In terms of absolute growth, both reveal growth patterns that follow: (1) an introduction period of slow growth, (2) a period of rapid growth, and (3) growth that approaches maturity or saturation (33:657). The key feature is that both models are able to depict the early and late developments in trend patterns. In terms of relative growth, the Pearl and the Gompertz functions are useful in displaying the growth patterns of mature technologies, that is, they depict growth that is constantly increasing at a decreasing rate (33:657).

The Pearl and Gompertz models differ in that the Pearl is more applicable in cases where growth is relatively rapid (33:657). Additionally, the Pearl function characteristically produces a symmetrical S-curve (29:230; 22:80). The Gompertz model, on the other hand, characteristically produces a nonsymmetrical S-curve (29:230; 22:81), and has greater value in situations where growth is relatively gradual (33:657).

Daniel and Wood propose an equation that describes a variety of nonlinear situations (8:22). Their function can be written as

$$y = ae^{b/x}$$

where a and b are parameter values, e is the base of the natural logarithm, and x is time.

Hoerl developed an equation used to describe non-linear growth trends (8:20-23). His equation states that

$$y = ax^b e^{cx}$$

where a, b, c are parameter values, e is the base of the natural logarithm, and x is time.

A simple and widely used expression for an S-curve is an equation stated by Makridakis and Wheelwright (25:169). As stated

$$y = e^{a + b/x}$$

where y is the S-curve estimate, a is the y-intercept, b is a value equivalent to the slope in the linear case, e is the base of the natural logarithm, and x is time. This equation is frequently used in long-term forecasting (25:169).

Finally, a polynomial equation could be developed to describe the nonlinear relationship within the pattern of time series data (8:8). A standard computerized linear regression program can accomplish this purpose. The general form of a polynomial regression equation with one independent variable can be written as follows:

$$y = a + b_1x + b_2x^2 + b_3x^3 + \ . \ . \ . + b_nx_n$$

Polynomial forms are described by their "degree" which is determined by the highest exponent in the equation (35:372). A rule-of-thumb states that the polynomial degree is related to the number of "bends" in the nonlinear curve (35:372). That is, "the maximum number of bends possible is always one less than the degree of the equation [35:372]." Therefore, a third-degree polynomial equation could theoretically explain the S-curve and its two bends as follows:

$$y = a + b_1x + b_2x^2 + b_3x^3$$

Polynomial equations are easy to fit, but are not typically used when the functional relationship of the variables are known (8:8, 20). Specialized nonlinear equations are more appropriate in nonlinear trends and generally provide better curve fits. However, the polynomial regression will be used in this research for the following reasons:

1. The specific nature of the time series sets is not known with absolute certainty at this point. Polynomial regression should guarantee nonlinear equations that fit the data sets reasonably well.

2. Since a polynomial equation is computed through a linear regression program, the statistical information provided by the standard program could become useful during data analysis.

Initially, it would intuitively appear that either the Pearl or the Gompertz function would be the most descriptive explanation of economic growth and provide the best curve fits, assuming the data sets form S-curve growth patterns. However, as a preliminary measure after graphing each data set, a curve will be fitted to an arbitrarily selected set using each of the aforementioned equations.

The equations with the best fits will then be used to fit curves to the remaining sets of time series data. The Statistical Package for the Social Sciences (SPSS) program on the Aeronautical Systems Division computer has linear and nonlinear regression subprograms capable of performing these tasks. The computer is a Control Data Corporation 6600 model.

Nonlinear regression and correlation will be used to explore the relationship between the independent and dependent variables in each time series. The polynomial will be the exception because it requires standard linear regression to develop its equation.

There are a number of similarities between linear and nonlinear regression. An overview of the former would help to understand the latter. Regression analysis is concerned with describing the nature of a relationship between dependent and independent variables while correlation analysis is concerned with investigating the strength of these relationships (15:357). Linear regression and correlation assume a linear relationship between variables. One objective of linear regression is to fit a regression line to a set of data.

Least squares is the most common method for fitting the regression line (35:278). This method determines the best fitting line by minimizing the algebraic sum of the squared vertical deviations of the observed data points from predicted values (35:278). The least squares procedure computes the corresponding parameter values for the line that provides the best fit. The idea is that the smaller the deviations of the observed values from the regression line, the tighter the line will be to the data pattern.

The general model for least squares linear regression is defined as:

$$y_i = B_o + B_1 x_i + e_i \qquad i = 1, 2, \ldots, n$$

The deviation of an observed value and its corresponding fitted value is called a residual or error term (e_i). The error terms are positive and negative values with respect to the regression line, and are squared in the least squares method in order to avoid having negative values in the calculations. Linear regression assumes the following:

1. The error terms are uncorrelated. Specifically, they are independent and normally distributed with a mean of zero and a constant variance (15:364-365).

2. The dependent variables are statistically independent of one another (8:7).

3. For any independent variable, the corresponding dependent variable is a normally distributed random variable (15:359).

One measure of strength in a linear relationship, or the "goodness of fit" of the regression line to the observed data, is a correlation statistic called the coefficient of determination. The coefficient of determination, r^2, measures the efficiency of the least squares fit of the dependent variables on the independent variables. The r^2 value is the ratio of the explained variation in a linear relationship to the total variation (15:397). In essence, the larger the ratio value, the better the degree of correlation between the dependent and independent variables in the linear equation. The overall explanatory power of the regression equation can also be measured by other statistical methods such as the F-test and the standard error of the estimate.

Nonlinear regression is similar to linear regression in that it also consists of minimizing the sum of squared deviations from the observed and predicted values (36:2). However, nonlinear least squares regression is required when some of the equation's parameters are nonlinear (8:9). Additionally, nonlinear regression is appropriate only if the form of the regression model is known with certainty (36:2). The general model for nonlinear least squares regression can be written as

$$y_i = f_i(x, b) + e_i \qquad i = 1, 2, \ldots, n$$

where $f_i(x, b)$ is the equation of the nonlinear model and e_i is the error term for the corresponding value of y_i (36:2).

The model is simply an arithmetic expression that combines the independent variables and the parameters. Nonlinear regression minimizes the sum of squares function, S(b), and in the process computes the appropriate parameter values. The nonlinear sum of squares function is shown as follows:

$$\text{MINIMIZE} \quad S(b) = \sum_{i=1}^{n} e_i^{\,2} = \sum_{i=1}^{n} [y_i - f_i(x,\ b)]^2$$

Nonlinear models pose difficulties in correlation analysis. First, in linear regression, the least squares estimators of parameter values are optimal because they are minimium variance unbiased estimators (1:183). Nonlinear regression, however, generally restricts such best estimators of the parameters (1:183). Only if the error terms are truly independent, normally distributed with a mean of zero and a uniform variance, will the nonlinear estimators also be the optimal, least squares estimators (1:183).

Second, the use of time series data in linear as well as nonlinear regression presents additional problems because it is often difficult to justify the assumption that dependent variables are independent of one another. The assumption of uncorrelated error terms is not appropriate because the error terms of a time series have a tendency to become correlated or dependent over time because the economic outcome for any given year is not entirely independent of the outcome for a previous year (32:352). For these two reasons goodness of fit measures such as the coefficient of determination and the F-test are meaningless in nonlinear regression and correlation. The SPSS nonlinear regression program, in fact, does not provide these statistics.

Nonlinear regression has two measures for the goodness of fit. The first measure is the sum of squares error (or residuals), and it is calculated by minimizing the nonlinear sum of squares function (1:184). The sum of squares error (SSE) is the algebraic sum of the squared deviations about the regression line or the unexplained variation in the regression function (15:375). In general, the smaller the SSE value, the better the goodness of fit in the regression function. However, the magnitude of the SSE value varies with the magnitude of the sample's observed values and the sample size. Therefore, the SSE is almost valueless in comparing the goodness of fit between dissimilar samples.

The second goodness of fit measure is the root mean square residual (RMSR). Synonomous terms for the RMSR are the root mean square error and the standard error of the estimate. The RMSR commonly measures the variation about the regression line, and is computed by taking the square root of the mean square residual (MSR). The MSR is equal to the SSE divided by the number of degrees of freedom in the sample (1:184).[2]

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[2]The degrees of freedom in nonlinear regression with a single dependent variable is the number of observations in the sample minus the number of parameters in the function (36:22).

Hence,

$$RMSR = \sqrt{MSR} = \sqrt{\frac{SSE}{\text{degrees of freedom}}}$$

Since the MSR is a measure of the variability of the error terms about the regression line, the RMSR becomes the standard deviation for a function's least squares fit (32:44-45). Basically,

$$RMSR = s$$

where s is the standard deviation (8:18). The smaller the RMSR value, the less dispersion of the error terms about the regression line and the better the goodness of fit.

The RMSR, however, is a relatively powerless statistic in attempting to compare the goodness of fit among samples of dissimilar size because the magnitude of the RMSR depends upon the degrees of freedom and the SSE, both of which in turn depend upon the sample size and the magnitude of the sample's observations. The SPSS nonlinear regression program provides the computed RMSR value in the printout.

The goodness of fit measure used in this research is the coefficient of variation (CV). The CV is a statistic that is independent of sample size, and is frequently used to compare the relative variability in different populations (33:89). The CV is usually expressed as a percent and calculated as a ratio of the sample's standard deviation to the mean value (33:89). Hence,

$$CV = \frac{s}{\bar{Y}}$$

where s is the sample's standard deviation and $\bar{Y}$ is the mean value of the dependent variables. Given the RMSR = s, the CV can be restated as follows:

$$CV = \frac{RMSR}{\bar{Y}}$$

Since the CV is a measure of the relative dispersion of data in one distribution with that of another, it can be used as a relative measure of the goodness of fit between several nonlinear functions with dissimilar sample sizes. Therefore, the lower the CV value, the more the fitted equation accounts for the dispersion of the residual terms in the equation and the better the goodness of fit. A CV of five percent or less would indicate that, overall, approximately two thirds of the observed values will be within ± five percent of the predicted values. The SPSS linear regression program provides the CV value in its printout. The nonlinear program does not.

Analysis of the Research Question

In Chapter 2, the general question presented in this research was stated as follows: Where on the technology life cycle growth curve does DMS occur? This question led to two, more specific questions.

1. Does DMS occur at or near the saturation level on the growth curve?

2. Does DMS occur at the same point regardless of technology?

Provided the research hypothesis proves valid, the equation(s) with the best explanatory power and goodness of fit will be selected to develop a smoothed S-curve for each data set. The appropriate DMS year will be marked on each curve.

The point at which DMS occurs will be defined as the percentage of the predicted cumulative sales during the technology's life cycle. This point will be determined by performing the following arithmetic operation:

$$\text{DMS Point} = \frac{\text{Predicted Cumulative Sales Volume at DMS}}{\text{Predicted Cumulative Sales Volume at Saturation}}$$

The predicted sales volume at DMS can be located in the computer printout of the chosen function with the best least squares fit and explanatory power. The predicted sales volume at saturation is simply the L parameter value in either the Pearl or the Gompertz formulas.

CHAPTER 4

ANALYSIS AND RESULTS

This chapter addresses four approaches for the treatment of data as described in the methodology. The first approach uses PPI statistics to convert dollar volume of sales figures to constant 1967 dollars. The second approach determines the functional form of the time series data by graphical plots. The third approach involves the use of least squares regression to fit equations to the time series data and the fourth approach analyzes the relationship of DMS and the growth curves. Findings will be used to test the research hypothesis and answer the research question.

Data Source

The data used in this research came from the Electronic Industries Association's (EIA) Electronic Industries Year Book 1969 and the 1979 Electronic Market Data Book. Two types of aggregate annual commercial sales data were located for each family of electronic components. The data types were annual sales volume and dollar volume of sales, and the component families were receiving tubes, germanium transistors, and germanium diodes/rectifiers. Therefore, six sets of data were available for analysis.

Data Availability

Commercial sales data on other families of electronic components were, for all practical purposes, unavailable in sufficient form to satisfy the first criterion for data acceptability as stated in Chapter 3. In general, aggregate sales data were incomplete, inconsistent, or too costly to obtain.

Two sources contained dollar volume of sales data on several families of electronic components. They were the January issues of Electronics magazine and the U.S. Department of Commerce's Current Industrial Report--Selected Electronic and Associated Products, Including Telephone and Telegraph Apparatus (MA--36N). However, the data in both publications were not extensive enough to form a consecutive time series that represented a reasonably complete life cycle for each component family. For example, both publications reported annual dollar volume of sales figures for the DTL family of bipolar logic circuits. However, proceeding back in time through successive annual issues, the annual reports end at 1972 and 1970 for the Department of Commerce publication and Electronics magazine, respectively. Prior to those dates, dollar volume of sales for DTL appeared to be incorporated in broader classifications such as "standard logic families, total."

Lack of foresight was a probable cause for the incompleteness of the time series data. That is, it appeared that a technology was not recognized, for reporting purposes, until it was well established in the market. Research analysts failed to keep pace with the rapid advance of integrated circuit technology in the 1960s and 1970s.

Inconsistency in data was another limiting factor. First, vacancies in the time series existed in several sources. For example, the Department of Commerce's publication reported quantities of DTL integrated circuits shipped for 1973 through 1976, but nothing before or after those dates. Second, various sources appeared to have different data collection methods. Data in the Electronics magazine could not be used to fill vacancies in the MA--36N report because of glaring differences in the magnitude of the data values.

Other publications, where data are given, showed similar problems of incompleteness and inconsistency. However, a few firms that specialized in data collection and analysis probably could have provided sufficient time series data for a substantial fee. One research firm quoted a price of $5,000 for the data expressed in Chapter 3.

PPI Application

Conversion of dollar volume of sales figures to a uniform expression of purchasing power was important in this research. Data adjustment consisted of two processes. First, index statistics with a 1967 index base were gathered for the 1930 to 1978 time frame. Second, the dollar volume of sales figures for the three families of electronic components were converted to uniform 1967 dollars. A base year of 1967 was chosen as a matter of convenience since the United States Government currently uses 1967 as the base year in many of its economic assessments (53).

A single publication containing 1967 based PPIs for the required time frame was not available. Therefore, four separate government sources and PPIs from three separate index bases were used to derive the 1967 index statistic base. The 1971 and 1979 issues of the Statistical Abstract of the United States contained 1967 based PPIs for 1940 through 1978 inclusive (52:333; 53:477). Since 1967 based PPIs were not available for 1930 through 1939, other index bases had to be shifted to the 1967 base. Furthermore, PPIs were taken from the "Industrial Commodities, all, except farm products and foods" listing in all four sources since there was no clearly delineated commodity for electronic components.

The 1970 Statistical Abstract of the United States contained 1957 based PPIs (1957-59=100) for 1940 through 1969 (51:339). Again, the PPIs for 1930 through 1939 were absent. However, the Statistical Abstract of the United States: Colonial Times to 1957 contained 1947 based PPIs (1947-49=100) for 1930 through 1939 (50:117). The overlap of the 1947 index base and the 1957 index base in year 1957 provided the means to splice or link the bases (14:608-609).

That is, a simple arithmetic procedure was used to calculate the missing PPIs for the 1957 base. The 1967 base could then be fully developed once the 1957 base was complete for 1930 through 1939.

The overlap of the 1947 based PPI series and the 1957 based PPI series in 1957 served as the basis to obtain the 1930 through 1939 PPIs for the 1957 base. First, a ratio was formed as follows:

$$\text{Ratio} = \frac{\text{1957 PPI in the 1947 Base}}{\text{1957 PPI in the 1957 Base}} = \frac{125.6}{99.2} = 1.266129$$

Second, the 1957 based PPIs for 1930 through 1939 were calculated by dividing the 1947 based PPIs for those years by the ratio value of 1.266129 (14:608-609).

A repetition of the procedures in the preceding paragraph provided the 1930-1939 PPIs for the 1967 base. The overlap of the 1957 based PPI series and the 1967 based PPI series in 1967 served as the new starting point in the procedure. All PPI statistics can be found in Appendix D.

The 1967 based PPIs were used to convert dollar volume of sales figures into constant 1967 dollars. A two-step procedure accomplished this purpose. First, for each dollar of sales figure, a conversion ratio was computed as follows:

$$\text{Conversion Ratio} = \frac{\text{Price index for 1967 (1967=100)}}{\text{Price index for the appropriate year}}$$

Second, the constant 1967 dollar value was calculated by multiplying the conversion ratio value by the appropriate dollar volume of sales figure (30:114). For example, germanium transistor dollar volume of sales for 1954 was converted to constant 1967 dollars as follows:

$$\text{Conversion Ratio} = \frac{100}{85} = 1.176$$

Dollar volume of sales for 1954 was $4.6M; therefore, multiplying $4.6M by 1.176, the dollar volume of sales in constant 1967 dollars was $5.4M. Appendix F contains the dollar volume of sales figures for the three families of electronic components.

Graphical Analysis

Each time series set was graphed with the Y-axis measuring cumulative sales data and the X-axis measuring time. Each of the six sets resembled an S-shaped curve with relatively rapid growth. See Appendix G.

Curve Fitting

A manual graph of each data set tentatively supported the hypothesis that the S-curve could adequately represent the life cycle curve. The problem then became one of finding the nonlinear equation or equations that best explained the underlying economic relationship of the time series variables in addition to providing the best fit of equation to data.

A trial run of the six equations presented in Chapter 3 provided a preliminary estimate of the equations that would satisfy the conditions of best explanation and data fit. Annual unit sales of germanium transistors was the arbitrarily selected data set for the trial run. The equations are restated as follows:

1. $y = L/(1 + ae^{-bx})$
2. $y = Le^{-bx^{-kx}}$
3. $y = ae^{b/x}$
4. $y = ax^{b}e^{cx}$
5. $y = e^{a + b/x}$
6. $y = a + b_1x + b_2x^2 + b_3x^3$

The equations with the best results were later used to fit curves to the remaining sets of time series data.

The first five equations required the use of the SPSS nonlinear regression program. The equations were transformed into FORTRAN arithmetic statements and specified on the "nonlinear" procedure card. The input medium for the data was card deck. The SPSS nonlinear program has the option whereby parameter estimates, if known, could be specified on the "parameters" procedure card. This procedure can reduce computer time and often yield better fits of equation to data (36:3). The program's output contained the following information: (1) the sum of squares error, (2) the RMSR statistic, (3) a table of residuals, (4) the predicted y-values, and (5) the estimated parameter values for the best fit of the equation to the observed data points. The parameters were determined by minimizing the nonlinear sum of the squares function.

The SPSS nonlinear regression procedure proved to be somewhat of an iterative trial and error process in two respects. First, the FORTRAN statements for the nonlinear functions sometimes required reformulation in order for the SPSS program to produce a useful output. For example, use of the Pearl equation's general form was necessary to obtain an output. Second, the best results were obtained when good estimates of the parameter values were specified on the parameters procedure card. Computations from logarithmic-linear regression, for example, proved useful when analyzing the $y = e^{a + b/x}$ function. However, initial estimates were often unavailable. This problem was overcome by reformulating the FORTRAN statements in order to get the program to produce a run. The final parameter values from the computer runs with reformulated equations were then used as estimates for the parameters procedure card, and the program was rerun with its original FORTRAN statement.

The sixth equation was the polynomial function. It required the use of the standard SPSS linear regression program with one small deviation. The time series had one independent variable while the third degree polynomial equation had three independent variables. Therefore, two "compute" statements were necessary to add the new variables.

The statements were as follows:

```
COMPUTE   VARX2=VARX*VARX
COMPUTE   VARX3=VARX2*VARX
```

The output of the linear program had a variety of statistical information, but only the following were of value in this research: (1) the coefficient of variation, (2) the mean response, and (3) the predicted y-values. Samples of some SPSS control card listings are displayed in Appendix H.

Table 3 shows results for the trial run on each of the six aforementioned equations. For unknown reasons, the nonlinear regression program would not produce an output for the Gompertz function.

TABLE 3

RESULTS OF TRIAL RUN

EQUATION	RMSR	CV
$y = L/(1 + ae^{-bx})$	24.80	2.05%
$y = Le^{-be^{-kx}}$	——	——
$y = ae^{b/x}$	231.36	19.12%
$y = ax^{b}e^{cx}$	24.47	2.02%
$y = e^{a + b/x}$	109.31	9.04%
$y = a + b_1x + b_2x^2 + b_3x^3$	76.37	6.31%

The following equations showed the best results in the trial run based on a CV of five percent or less.

$$y = ax^b e^{cx}$$

$$y = L/(1 + ae^{-bx})$$

These equations were chosen for further least squares regression of the remaining time series data sets, the results of which are shown in Table 4.

TABLE 4

REGRESSION RESULTS ON ALL DATA SETS

DATA SET	$y = ax^b e^{cx}$	$y = L/(1 + ae^{-bx})$
Transistor Sales	2.02%*	2.05%
Transistor DVS	2.06%*	4.33%
Diode Sales	5.03%	2.01%*
Diode DVS	1.80%*	3.65%
Receiving Tube Sales	4.91%	2.04%*
Receiving Tube DVS	4.74%	1.74%

*Best fit.

Each equation produced a tight fit for each time series data set. For all data sets, with one small exception, both the Hoerl equation ($y = ax^b e^{cx}$) and the Pearl equation ($y = L/(1 + ae^{-bx})$) had fits with a five percent or less CV. However, it appeared that the Pearl function had the best overall fit. This result substantiates the theoretical ability of the Pearl function to mathematically explain the underlying nature of economic growth. Additionally, there appeared to be no observable difference between the growth patterns produced by annual unit sales and the patterns produced by dollar volume of sales.

These results therefore support the research hypothesis that the S-curve can represent the life cycle development of a technology, and that a nonlinear equation can be fitted to the annual commercial sales data for that technology using the least squares regression technique.

<u>DMS/Growth Curve Relationship</u>

The Pearl function was used to develop a smooth growth curve for each data set. Appendix I contains these graphs. A mark was placed on each growth curve to represent the point at which DMS occurred for that family of electronic components. The first major DMS case for receiving tubes occurred in 1970, and 1975 was the DMS year for germanium transistors and germanium diodes (45).

A problem immediately appeared in this analysis. DMS for the transistor and diode families occurred in 1975; however, data were unavailable after 1972. Data for the missing years (1973, 1974, and 1975) were extrapolated by substituting the values into the equation. This procedure was deemed appropriate because only three data points were absent, and they were extremely close in value to the estimated saturation level of each S-curve.

The DMS point for each S-curve was defined as the percentage of predicted cumulative sales during the technology's life cycle, and calculated as follows:

$$\text{DMS Point} = \frac{\text{Predicted Cumulative Sales Volume at DMS}}{\text{Predicted Cumulative Sales Volume at Saturation (L)}}$$

The predicted sales volume at DMS came from the computer printouts of the nonlinear regression program. The predicted sales volume at saturation was the final parameter value for L (B(1)) in the appropriate printout. The percentage of life cycle sales at DMS for each data set are shown in Table 5.

TABLE 5

PERCENTAGE OF LIFE CYCLE SALES AT DMS

DATA SET	Predicted Sales Volume (Cum.) at DMS	Predicted Sales Volume (Cum.) at Saturation	Percentage Sales at DMS
Transistor Sales	2,972.34M	2,975.00M	99.9%
Transistor DVS	$2,022.01M	$ 2,030.12M	99.6%
Diode Sales	4,442.41M	4,571.98M	97.0%
Diode DVS	$ 481.59M	$ 486.70M	98.9%
Receiving Tube Sales	10,441.78M	12,404.50M	84.2%
Receiving Tube DVS	$8,604.05M	$10,087.05M	85.3%

DMS occurred near the predicted saturation level of each growth curve. For all practical purposes, DMS for germanium transistors and germanium diodes occurred at the saturation level. DMS for receiving tubes was at the 84 to 85 percent level of predicted total growth. DMS did not occur at the same point for the three technologies.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

DMS is a situation that occurs when the last manufacturing source discontinues or intends to discontinue production of items required to logistically support the DOD's weapon systems. The DMS problem exists in many DOD managed items, but it is more severe in electronic components because of the rapid advance of electronics technology.

DMS is an economic problem in two respects. First, on an aggregate level, the rapid pace of technological innovation continually generates components with greater functional capabilities. Therefore, demand constantly shifts from the older to the newer products. The resultant decline in the profitability of the older components is the direct cause of obsolescence. Furthermore, the expansion of existing markets and/or the capture of new markets are the incentives for manufacturers to maintain the accelerated pace of technological innovation.

Second, DMS is an economic burden on the DOD. Each year the logistics support of greater numbers of DOD weapon systems becomes much more difficult and expensive because manufacturers are forced to discontinue the production of the older, unprofitable electronic devices. The number of

DMS cases continues to grow annually, with the net result that increased manpower, time, and monetary resources are devoted to resolving the DMS problem. Insufficient time to explore the available alternatives often necessitates a LOT purchase in order to insure continued logistics support. The main problem with LOT buys is that it drains key stock fund monies.

DMS is a growing problem. The number of DMS cases continues to grow annually, and increased millions of dollars are spent every year on LOT purchases. DMS is a DOD-wide problem, and it is not confined to relatively obsolete military equipment. Electronic components contained in such weapon systems as the F-15, F-16, and the E-3A aircraft have already been subjected to this problem. DMS will continue to be a problem for DOD as long as the commercial electronics market remains the driving force in the direction of mainstream technology. However, the severity of this challenging problem can be minimized through the judicious use of sound management techniques.

The need to anticipate, rather than respond, to a DMS case is paramount. Advance knowledge of the likelihood of a DMS situation could enhance DESC's operation and enable management to plan anticipatory measures. Additionally, substantial cost savings could be realized if DESC had greater time to pursue all the available alternatives when confronted with a DMS case. Therefore, this research investigated one approach to lessen the severity of DMS; that is, the research objective was to develop a practical method of forecasting a DMS situation.

The research methodology incorporated the use of a technological forecasting technique called trend extrapolation. The intent was to investigate the life cycle growth curves for three technologies of obsolete electronic components, and to determine mathematical equations that best explained the relationship between the independent and dependent variables of the curves. The growth curves were actually time series arrangements because time was the independent variable in the growth curve relationship. Annual aggregate commercial sales data for each of the three technologies formed the time series. Aggregate data were the logical and only choice in developing a practical forecasting method because other types of data such as cost/profit figures are generally regarded as proprietary information by manufacturers. Once the growth curves were formed and the mathematical relationships determined, the curves were then examined to determine the feasibility of using them to predict DMS.

Conclusions

The research hypothesis proved valid. The aggregate commercial sales data for the three families of electronic components studied in this research followed predictable growth patterns which can be characteristically described in terms of an S-shaped curve. There was no observable difference between the growth patterns produced by annual unit sales and the patterns produced by dollar volume of sales. The Pearl function appeared to offer the best mathematical explanation of the underlying economic nature of each time series growth curve in addition to providing the best overall data fit.

No substantial conclusions can be drawn from the research question. DMS occurred at or near the growth curve saturation level for each technology. However, DMS for receiving tubes occurred at the 84 to 85 percent level while DMS for germanium transistors and germanium diodes occurred at the predicted saturation level. DMS did not occur at the same level for each technology as expected, but a reasonable conclusion cannot be based on only three sample technologies. Many reasons could exist for this disparity. One logical explanation may be the fact that receiving tube technology had an established market for at least 50 years prior to DMS while the market for the germanium products was roughly 20 years old. Receiving tubes could hardly be expected to vanish over night. However, research on more samples would provide additional insight into the research question. If nothing else, a frequency distribution for the occurrence of DMS on the growth curve could be established. A frequency distribution of 30 or more samples should lead to a probabilistic way to access the likelihood of DMS.

This research does conclude that there is a basis for continued study in this area. An initial step toward developing any technological forecasting approach based on trend extrapolation is the requirement for the presence of an observable trend in historic activity. This research confirms, that based on three samples of different technologies, there is a predictable pattern of economic growth in component technology that can best be explained by the Pearl function. The main limitation in any future study will be the availability of data.

It appears feasible that a method can be developed to forecast DMS for a technology of electronic components. An individual with a knowledge of the trends in electronic technology could monitor trade journals and periodicals and judiciously categorize the technologies for potential analysis. Such an individual could also conduct the search for relevant data. Forecasting DMS would begin when the data indicate that a technology is clearly in the declining stage of its life cycle. The combination of predictable growth described by a mathematical function, and a probability distribution for the occurrence of DMS, would be the necessary ingredients for developing a forecast. The accuracy of the forecast would improve with periodic additions to the time series data base.

The forecasting method theorized in the preceding paragraph would only provide forecasts on broad technologies because of data availability. Such a method could be beneficial to DESC, but would probably be of greater value to the planners concerned with introducing new weapon systems into the military inventory. In order to minimize the severity of DMS, the type of component technology to be incorporated and the logistics support for those components need to be considered in the design and development stage of a weapon system.

Recommendations

The 1979 Study of the Influence of Technological Change and Diminishing Manufacturing Sources on DOD Electronics Parts Support performed by DESC contains numerous recommendations for combating the DMS problem. A few of those recommendations will be reiterated in this report because they appear to be major problems that deserve special attention. Furthermore, several of them could become suitable topics for future research.

Any type of forecasting is contingent upon being able to associate a technology with its national stock numbers or supply nomenclature, and vice versa. Presently, catalog descriptions for countless families of electronic components, particularly integrated circuits, are inadequate for identifying the prominent technological features. For example, many integrated circuits are simply described as microcircuit linear or microcircuit digital, and accompanied by physical descriptions of the devices. Components are not described as diode-transistor-logic or 1K random access memories for example. Thus, it is nearly impossible to think in terms of technology in dealing with the federal supply system.

The problem of DMS needs to be initially addressed during the design and development of new weapon systems. It is pointless to incorporate obsolete, or soon-to-be obsolete, components into systems before full-scale deployment. Consideration of DMS in the design stage is just one way to reduce some of the long-run difficulties of logistics support. Along these lines, every consideration should be given where possible to acquiring parts that follow the developments in mainstream technology. The use of standardized parts and electronic modules where possible can also help to reduce the complexity of the problem.

Finally, there is an urgent requirement for DESC's customers to develop an automated means of determining the LOT demand for a DMS item. The information required to calculate the LOT quantity is as follows: (1) the number of systems supported by the component(s), (2) the number of components required to support a system, and (3) the phase out date of the affected system(s). In most cases, this information has to be manually extracted--a process which is very time-consuming.

Recommendations for Future Research

As stated earlier, the 1979 DESC Study of the Influence of Technological Change and Diminishing Manufacturing Sources on DOD Electronics Parts Support contains many recommendations that need to be pursued more vigorously. Also, some already studied areas require additional research. Many of these recommendations could become suitable topics for future student research.

Several families of electronic components exhibit a process of multilevel technological substitution; that is, a particular technology is replacing an older one while at the same time being replaced by a newer one. Microprocessors and memory chips are examples of this phenomenon. Sharif and Kabir (1976) describe a system dynamics model that can be used to forecast multilevel technological substitution. The aforementioned families of electronic components, and others that may exhibit this phenomenon, would be ideal candidates for research that incorporates this model. The main limitation would be the availability of data.

Several U.S. corporations such as Boeing and Honeywell promote the use of technological forecasting in their planning activities. Research could be conducted to determine what techniques and for what purposes they are used, how effective the techniques have been, and determine the feasibility of incorporating them in DOD planning.

Finally, this research concentrated on developing a practical method of forecasting a DMS situation. It was also stated that such a technique would probably have greater applicability in designing new weapon systems. Assuming that a practical method of forecasting a DMS situation can eventually be developed, future research could therefore consider some of the following questions:

1. Since DMS is a problem that exists throughout DOD, it would seem plausible that the forecasting effort would be concentrated at the DOD level so that overall guidance can be disseminated to the Armed Services. The question is at what level, and where, in DOD the forecasting should be accomplished in order to achieve the greatest benefit.

2. Should guidance on DMS matters be given to DOD's contractors, and in what form? Presently, many weapon systems are acquired by contractually stating the performance specifications and allowing the contractor the freedom to design the equipment to meet the specified performance requirements. It is not unusual for DOD to receive new equipment that already has obsolete parts. Essentially, the problem becomes one of how to incorporate the concern for DMS in the life cycle support of new systems so that they can become logistically supportable with a minimum of problems.

DMS is a problem that will continue to grow. Additional research in some areas is required, and actions need to be implemented in others before the problem drains even greater resources and eventually becomes unmanageable. Now is the time to begin these efforts.

APPENDICES

APPENDIX A

DESC ALTERNATIVES IN DMS SITUATIONS[1]

[1]These alternatives were presented in the Study of the Influence of Technological Change and Diminishing Manufacturing Sources on DOD Electronics Parts Support, pp. 95-101.

1. Encourage the manufacturer to continue production.

2. Attempt to find new manufacturing sources. This may include a search of other electronic industry and nonindustry sources as well as small businesses and foreign manufacturers. Government regulations prohibit a foreign manufacturer from becoming the sole source of an electronic component.

3. Level load the DMS item with other related items in order to increase the size of the procurement. Essentially, the government guarantees other business with the manufacturer in order to keep the production line open.

4. Find a suitable substitute for the DMS item.

5. Modify or redesign the affected end-item equipment or DMS item.

6. Cannibalize the DMS components from other equipment.

7. Consider deletion when the equipment is old and in limited quantity.

8. Utilize government-owned, contractor-operated or government-owned, government-operated facilities. For example, the Tobyhanna Army Depot and the Naval Ocean Systems Center have the capabilities to manufacture limited quantities of crystals and integrated circuits, respectively.

9. Exercise the life of type (LOT) buy option. This is the one-time purchase of a sufficient quantity of the DMS item to support the affected end-item until inventory phase-out. This option is usually exercised after all other alternatives have been studied.

APPENDIX B

DEFINITIONS

Analog--Indicates continuous, non-digital representation of phenomena. For example, an analog voltage may take any value (17:91).

Binary--A system of numbers using 2 as a base in contrast to the decimal system which uses 10 as a base. The binary system requires only two symbols . . . 0 and 1 (17:91).

Bipolar--Refers to transistors that are manufactured with two types of semiconductor substrate material (17:91).

Bit--A binary digit. A bit is the smallest unit of storage in a digital computer and is used to represent one of the two digits in the binary number system (17:91).

CMOS--Complementary Metal Oxide Semiconductor (MOS). A logic family made by combining N-channel and P-channel MOS transistors (17:91).

CPU--Central Processor Unit. That part of a computer that fetches, decodes, and executes program instructions and maintains status of results (17:91).

Chip--A single square or rectangular piece of semiconductor material into which a specific electrical circuit has been fabricated. Also called a die (17:91).

Diode--An electronic device, having two terminals, between which an electric current can pass readily in one direction but not in the other. Diodes are useful in converting alternating current into direct current (57:32).

Discrete--A semiconductor device containing only one active device, such as a transistor or diode (17:91).

Dopant--An element which, when incorporated in a semiconducting crystal, strongly enhances its ability to conduct electricity (57:132).

Integrated circuit--An array of diodes, transistors, and possibly other circuit components, all formed by common processes in a single piece of silicon crystal, arranged and interconnected to perform the function of an electronic circuit (57:132).

MOS--Metal Oxide Semiconductor. Devices using unipolar transistors in which only one kind of charge carrier is active in a single device (28:76).

NMOS--N-channel MOS. In this type of MOS device, electrons are used to conduct current (28:76).

PMOS--P-channel MOS. In this type of MOS device, positive-charged bodies called holes are used to conduct current (28:76).

Receiving tube--A type of electron tube that operates on relatively low voltage and consumes low power (12:5, 7).

Semiconductor--(1) A material with properties of both a conductor and an insulator. (2) All electronic components that have semiconductor materials including integrated circuits. (3) Only discrete components such as transistors and diodes that have semiconductor materials (57:132).

Transistor--A solid-state electronic device, usually having three terminals, in which a small current flow proportionally controls the magnitude of a much larger current (57:132).

Unipolar--A semiconductor material which utilizes charge carriers of only one polarity (28:76).

APPENDIX C

DATA SEARCH--SOURCES AND METHODS OF CONTACT

1. Electronic periodicals.
   a. Examination of every January issue of Electronics magazine from 1962 to 1981.
   b. Telephone calls to the editors of the following publications:
      (1) Electronics magazine.
      (2) Electronic Business.
      (3) Journal of Electronic Defense.
      (4) Electronics Design.
      (5) Electronic Trend Publications, Inc.

2. Industry trade associations. Telephone conversations and letter correspondence with the following:
   a. Electronics Industry Association. Telephone and letter contact.
   b. Semiconductor Industry Association. Telephone and letter contact.
   c. Integrated Circuit Engineering Corporation. Telephone and letter contact.
   d. SEMI (Semiconductor Equipment and Materials Institute). Letter contact.
   e. American Electronics Association. Telephone contact.

3. The following military organizations were contacted:
   a. Air Force Avionics Laboratory, Microelectronics Branch, Wright-Patterson AFB, OH.
   b. Air Force Materials Laboratory, Electronics Branch, Wright-Patterson AFB, OH.
   c. Air Force Electronic Systems Division, Hanscom Field, MA.
   d. Air Force Acquisition Logistics Division, Avionics and Electronics Branch, Wright-Patterson AFB, OH.
   e. Naval Avionics Center, Indianapolis, IN.
   f. U.S. Army Electronics and Research Division, Fort Monmouth, NJ.
   g. Rome Air Development Center (USAF), Griffis AFB, NY.

4. U.S. Government agencies.
   a. U.S. Department of Commerce, Cincinnati Field Office. Personal visit.
   b. U.S. Department of Commerce, Washington, DC. Personal visit.
   c. U.S. Bureau of the Census, Washington, DC. Telephone contact.
   d. U.S. Library of Congress, Washington, DC. Telephone contact and personal visit.

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AN INVESTIGATION OF TIME SERIES GROWTH CURVES AS A PREDICTOR OF--ETC(U)
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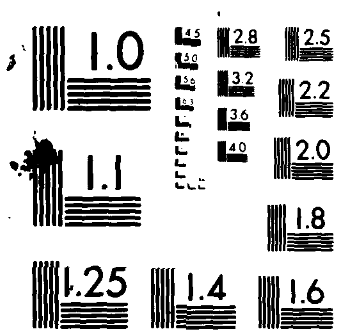
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

6. Manufacturers.
    a. Texas Instruments Corporation. Telephone contact.
    b. Motorola, Inc. (Semiconductor Group). Telephone contact.
    c. Fairchild Semiconductor. Telephone contact.

7. Independent research firms.
    a. Dataquest, Inc. Telephone contact.
    b. Gnostic Concepts, Inc. Telephone contact.
    c. Frost & Sullivan, Inc. Letter and telephone contact.
    d. Technology Analysis Group. Telephone contact.
    e. MITRE Corporation. Telephone contact.

APPENDIX D

PRODUCER PRICE INDEXES

YEAR	1947 Base (1947-49=100)	1957 Base (1957-59=100)	1967 Base (1967=100)
1930	60.9	48.1	45.2
1931	53.6	42.3	39.8
1932	50.2	39.6	37.3
1933	50.9	40.2	37.8
1934	56.0	44.2	41.6
1935	55.7	44.0	41.4
1936	56.9	44.9	42.2
1937	61.0	48.2	45.3
1938	58.4	46.1	43.7
1939	58.1	45.9	43.2
1940	59.4	46.8	44.0
1941	63.7	50.3	47.3
1942	68.3	53.9	50.7
1943	69.3	54.7	51.5
1944	70.4	55.6	52.3
1945	71.3	56.3	53.0
1946	78.3	61.7	58.0
1947	95.3	75.3	70.8
1948	103.4	81.7	76.9
1949	101.3	80.0	75.3
1950	105.0	82.9	78.0
1951	115.9	91.5	86.1
1952	113.2	89.4	84.1
1953	114.0	90.1	84.8
1954	114.5	90.4	85.0
1955	117.0	92.4	86.9
1956	122.2	96.5	90.8
1957	125.6	99.2	93.3
1958		99.5	93.6
1959		101.3	95.3
1960		101.3	95.3
1961		100.8	94.8
1962		100.8	94.8
1963		100.7	94.7
1964		101.[illegible]	95.2
1965		102.5	96.4
1966		104.7	98.5
1967		106.3	100.0
1968		109.0	102.5
1969		112.7	106.0
1970			110.0
1971			114.0
1972			117.9
1973			125.9

YEAR	1947 Base (1947-49=100)	1957 Base (1957-59=100)	1967 Base (1967=100)
1974			153.8
1975			171.5
1976			182.4
1977			195.1
1978			209.4

Sources: The index statistics were derived from four separate editions of U.S. Bureau of the Census' Statistical Abstract of the United States.

APPENDIX E

UNIT SALES DATA FOR GERMANIUM TRANSISTORS, GERMANIUM DIODES, AND RECEIVING TUBES[2]

[2]Source: Electronic Industries Association's (EIA) Electronic Industries Year Book 1969 (10:57, 66, 67) and the 1979 Electronic Market Data Book (11:88, 108).

NOTE: "Due to inadequate industry participation, the EIA Solid State Products Division found it necessary to suspend publication of all marketing services reports effective January 1, 1973 [11:103]." Therefore, sales data on germanium transistors and germanium diodes are not available up to the year of DMS--1975.

Germanium Transistors--Unit Sales

YEAR	No. of Sales (in millions)	Cumulative Sales (in millions)
1954	1.3	1.3
1955	3.6	4.9
1956	12.4	17.3
1957	27.7	45.0
1958	45.0	90.0
1959	77.5	167.5
1960	119.1	286.6
1961	177.9	464.5
1962	213.7	678.2
1963	249.4	927.6
1964	288.8	1,216.4
1965	333.6	1,550.0
1966	368.7	1,918.7
1967	270.3	2,189.0
1968	199.3	2,388.3
1969	208.5	2,596.8
1970	135.8	2,732.6
1971	88.2	2,820.8
1972	69.9	2,890.7

Germanium Diodes--Unit Sales

YEAR	No. of Sales (in millions)	Cumulative Sales (in millions)
1956	30.0	30.0
1957	41.2	71.2
1958	45.8	117.0
1959	66.5	183.5
1960	118.3*	301.8
1961	171.4	473.2
1962	192.0	665.2
1963	228.5	893.7
1964	283.5	1,177.2
1965	383.1	1,560.3
1966	527.0	2,087.3
1967	440.1	2,527.4
1968	440.8	2,968.2
1969	435.8	3,404.0
1970	369.5	3,773.5
1971	172.5	3,946.0
1972	178.5	4,124.5

*Estimated value from log-linear regression on a Texas Instruments Business Analyst-I hand calculator.

Receiving Tubes--Unit Sales

YEAR	No. of Sales (in thousands)	Cumulative Sales (in thousands)
1922	1,000	1,000
1923	4,500	5,500
1924	12,000	17,500
1925	20,000	37,500
1926	30,000	67,500
1927	41,200	108,700
1928	50,200	158,900
1929	69,000	227,900
1930	40,213	268,113
1931	47,696	315,809
1932	47,453	363,262
1933	62,762	426,024
1934	63,247	489,271
1935	75,962	565,233
1936	98,304	663,537
1937	92,056	755,593
1938	74,691	830,284
1939	98,500	928,784
1940	108,476	1,037,260
1941	135,838	1,173,098
1942	107,747	1,280,845
1943	110,078	1,390,923
1944	129,063	1,519,986
1945	139,478	1,659,464
1946	205,217	1,864,681
1947	199,534	2,064,215
1948	204,720	2,268,935
1949	198,753	2,467,688
1950	382,961	2,850,649
1951	375,644	3,226,293
1952	368,519	3,594,812
1953	437,091	4,031,903
1954	385,089	4,416,992
1955	479,802	4,896,794
1956	464,186	5,360,980
1957	456,424	5,817,404
1958	397,366	6,214,770
1959	432,936	6,647,706
1960	393,055	7,040,761
1961	375,006	7,415,767
1962	361,239	7,777,006
1963	395,544	8,172,550

Receiving Tubes--Unit Sales (Continued)

YEAR	No. of Sales (in thousands)	Cumulative Sales (in thousands)
1964	368,088	8,540,638
1965	396,552	8,937,190
1966	442,879	9,380,069
1967	323,349	9,703,418
1968	301,626	10,005,044
1969	280,883	10,285,927
1970	231,403	10,517,330
1971	223,407	10,740,737
1972	199,132	10,939,869
1973	167,998	11,107,867
1974	123,656	11,231,523
1975	91,341	11,322,864
1976	79,754	11,402,618
1977	76,070	11,478,688
1978	68,828	11,547,516

APPENDIX F

DOLLAR VOLUME OF SALES (DVS) FOR
GERMANIUM TRANSISTORS,
GERMANIUM DIODES, AND
RECEIVING TUBES[3]

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[3]Source: Electronic Industries Association's (EIA) Electronic Industries Year Book 1969 (10:57,66,67) and the 1979 Electronic Market Data Book (11:88,108).

NOTE: "Due to inadequate industry participation, the EIA Solid State Products Division found it necessary to suspend publication of all marketing services reports effective January 1, 1973 [11:103]." Therefore, sales data on germanium transistors and germanium diodes is not available up to the year of DMS--1975.

Germanium Transistor DVS

Year	DVS (in millions)	Index No. (1967=100)	DVS--Constant 1967 Dollars	Cumulative DVS
1954	$ 4.6	85.0	$ 5.41	$ 5.41
1955	10.3	86.9	11.85	17.26
1956	29.1	90.8	32.05	49.31
1957	51.4	93.3	55.09	104.40
1958	80.7	93.6	86.22	190.62
1959	151.8	95.3	159.29	349.91
1960	202.5	95.3	212.49	562.40
1961	202.0	94.8	213.08	775.48
1962	174.8	94.8	184.39	959.87
1963	171.1	94.7	180.68	1,140.55
1964	163.2	95.2	171.43	1,311.98
1965	166.4	96.4	172.61	1,484.59
1966	164.5	98.5	167.00	1,651.59
1967	116.2	100.0	116.20	1,767.79
1968	81.4	102.5	79.44	1,847.23
1969	77.7	106.0	72.64	1,919.87
1970	55.8	110.0	50.73	1,970.60
1971	40.7	114.0	35.70	2,006.30
1972	36.4	117.9	30.87	2,037.17

Germanium Diode DVS

Year	DVS (in millions)	Index No. (1967=100)	DVS--Constant 1967 Dollars	Cumulative DVS
1956	$19.6	90.8	$21.59	$21.59
1957	29.5	93.3	31.62	53.21
1958	27.6	93.6	29.49	82.70
1959	31.8	95.3	33.37	116.07
1960	37.49*	95.3	39.34	155.41
1961	47.3	94.8	49.89	205.30
1962	34.3	94.8	36.18	241.48
1963	33.1	94.7	34.95	276.43
1964	32.5	95.2	34.14	310.57
1965	30.0	96.4	31.12	341.69
1966	35.3	98.5	35.84	377.53
1967	26.4	100.0	26.40	403.93
1968	23.7	102.5	23.12	427.05
1969	21.9	106.0	20.66	447.71
1970	18.4	110.0	16.73	464.44
1971	6.5	114.0	5.70	470.14
1972	6.3	117.9	5.34	475.48

*Estimated value from log-linear regression on a Texas Instruments Business Analyst I hand calculator.

Receiving Tube DVS

Year	DVS (in thousands)	Index No. (1967=100)	DVS--Constant 1967 Dollars	Cumulative DVS
1930	$ 37,930	45.2	$ 83,916	$ 83,916
1931	25,505	39.8	64,083	147,999
1932	18,299	37.3	49,059	197,058
1933	23,147	37.8	61,235	258,293
1934	23,315	41.6	56,046	314,473
1935	25,565	41.4	64,167	378,640
1936	31,942	42.2	75,692	454,332
1937	29,871	45.3	65,940	520,272
1938	23,093	43.7	52,844	573,116
1939	27,985	43.2	64,780	637,896
1940	27,610	44.0	62,750	700,646
1941	47,500	47.3	100,422	801,068
1942	43,000	50.7	84,813	885,881
1943	51,000	51.5	99,029	984,910
1944	62,140	52.3	118,815	1,103,725
1945	68,500	53.0	129,245	1,232,970
1946	101,000	58.0	174,138	1,407,108
1947	107,000	70.8	151,130	1,558,238
1948	112,000	76.9	145,644	1,703,882
1949	119,000	75.3	158,035	1,861,917
1950	250,000	78.0	320,513	2,182,430
1951	261,000	86.1	303,136	2,485,566
1952	259,116	84.1	308,105	2,793,671
1953	303,675	84.8	358,107	3,151,778
1954	275,999	85.0	324,705	3,476,483
1955	358,110	86.9	412,094	3,888,577
1956	374,186	90.8	412,099	4,300,676
1957	384,402	93.3	412,006	4,712,682
1958	341,929	93.6	365,309	5,077,991
1959	368,872	95.3	387,064	5,465,055
1960	331,742	95.3	348,103	5,813,158
1961	311,098	94.8	328,162	6,141,320
1962	301,525	94.8	318,064	6,459,384
1963	297,000	94.7	313,622	6,773,006
1964	272,000	95.2	285,714	7,058,720
1965	282,000	96.4	292,513	7,351,251
1966	301,000	98.5	305,584	7,656,835
1967	210,000	100.0	210,000	7,866,835
1968	196,000	102.5	191,220	8,058,055
1969	283,691	106.0	267,633	8,325,688
1970	259,171	110.0	235,610	8,561,298
1971	261,386	114.0	229,286	8,790,584

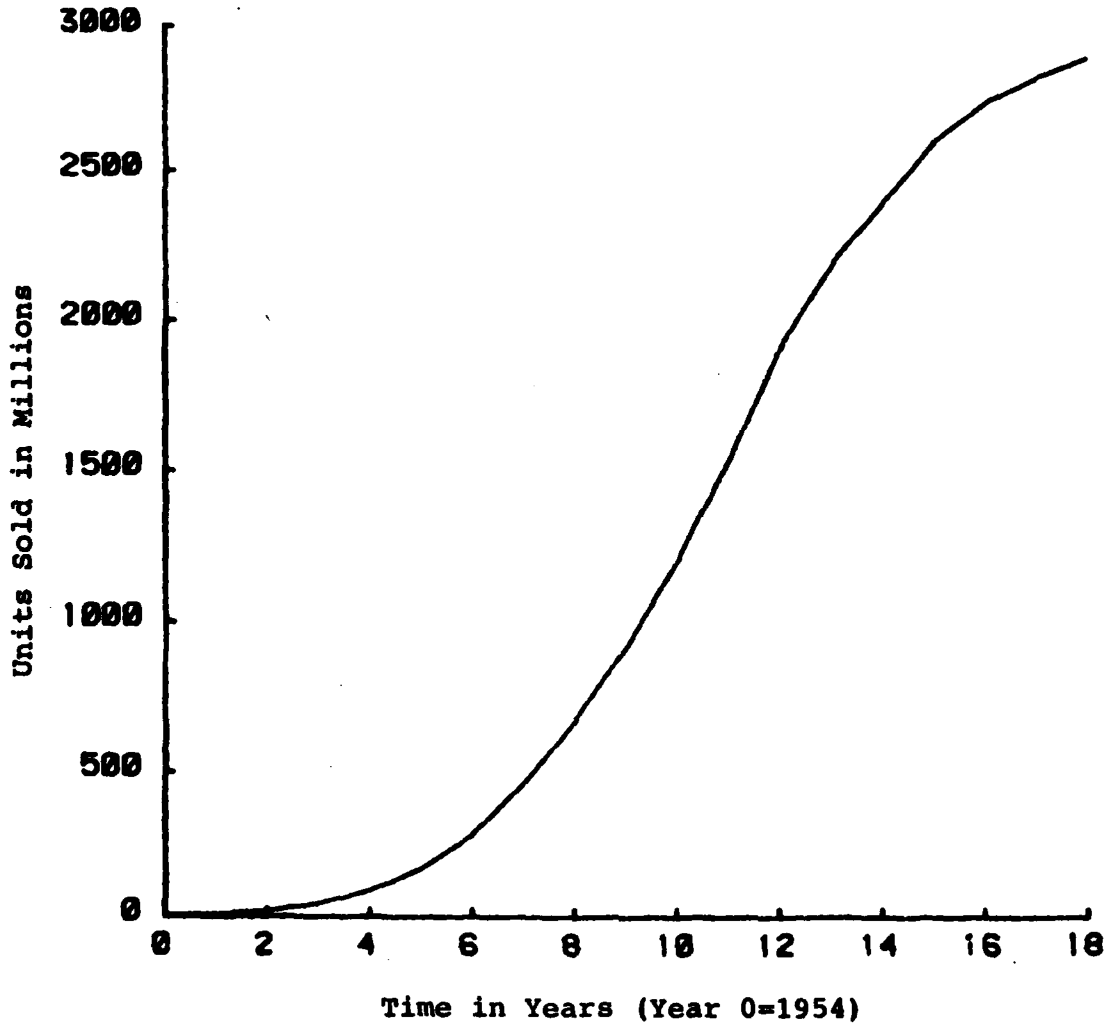
Receiving Tube DVS (Continued)

Year	DVS (in thousands)	Index No. (1967=100)	DVS--Constant 1967 Dollars	Cumulative DVS
1972	240,950	117.9	204,368	8,994,952
1973	204,244	125.9	162,227	9,157,179
1974	167,157	153.8	108,685	9,265,864
1975	152,215	171.5	88,755	9,354,619
1976	139,513	182.4	76,487	9,431,106
1977	143,772	195.1	73,691	9,504,797
1978	134,455	209.4	64,210	9,569,007

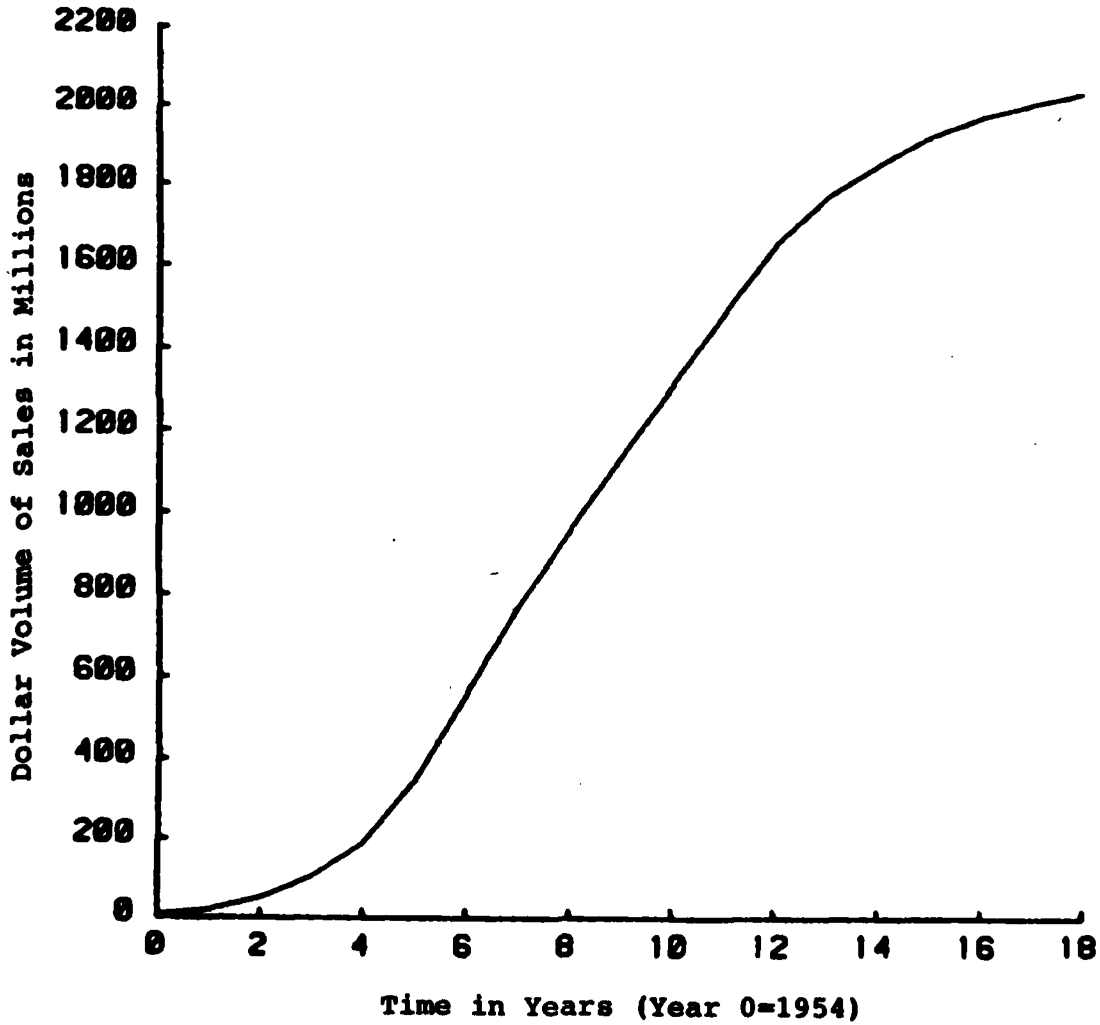
APPENDIX G

GROWTH CURVES FOR ACTUAL TIME SERIES DATA

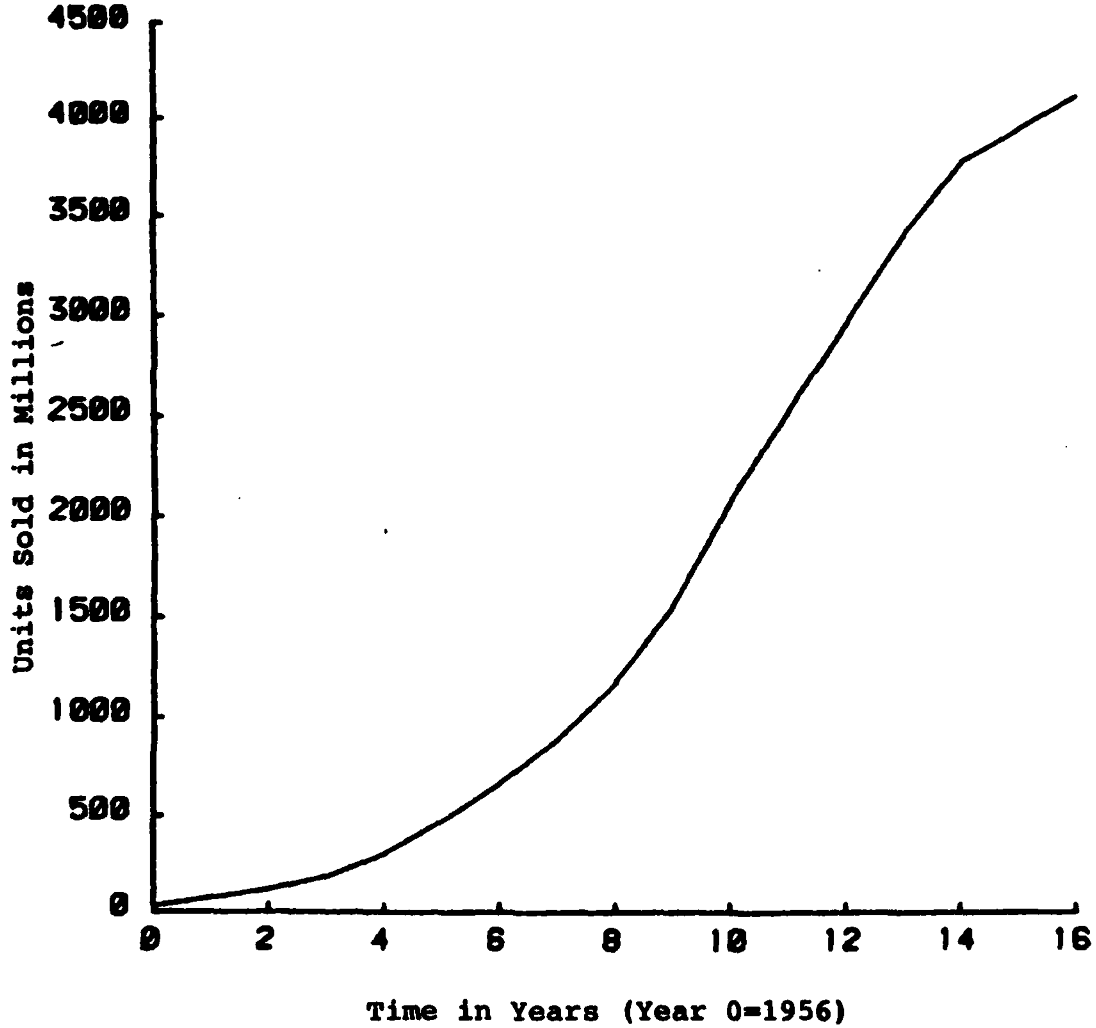
GERMANIUM TRANSISTORS

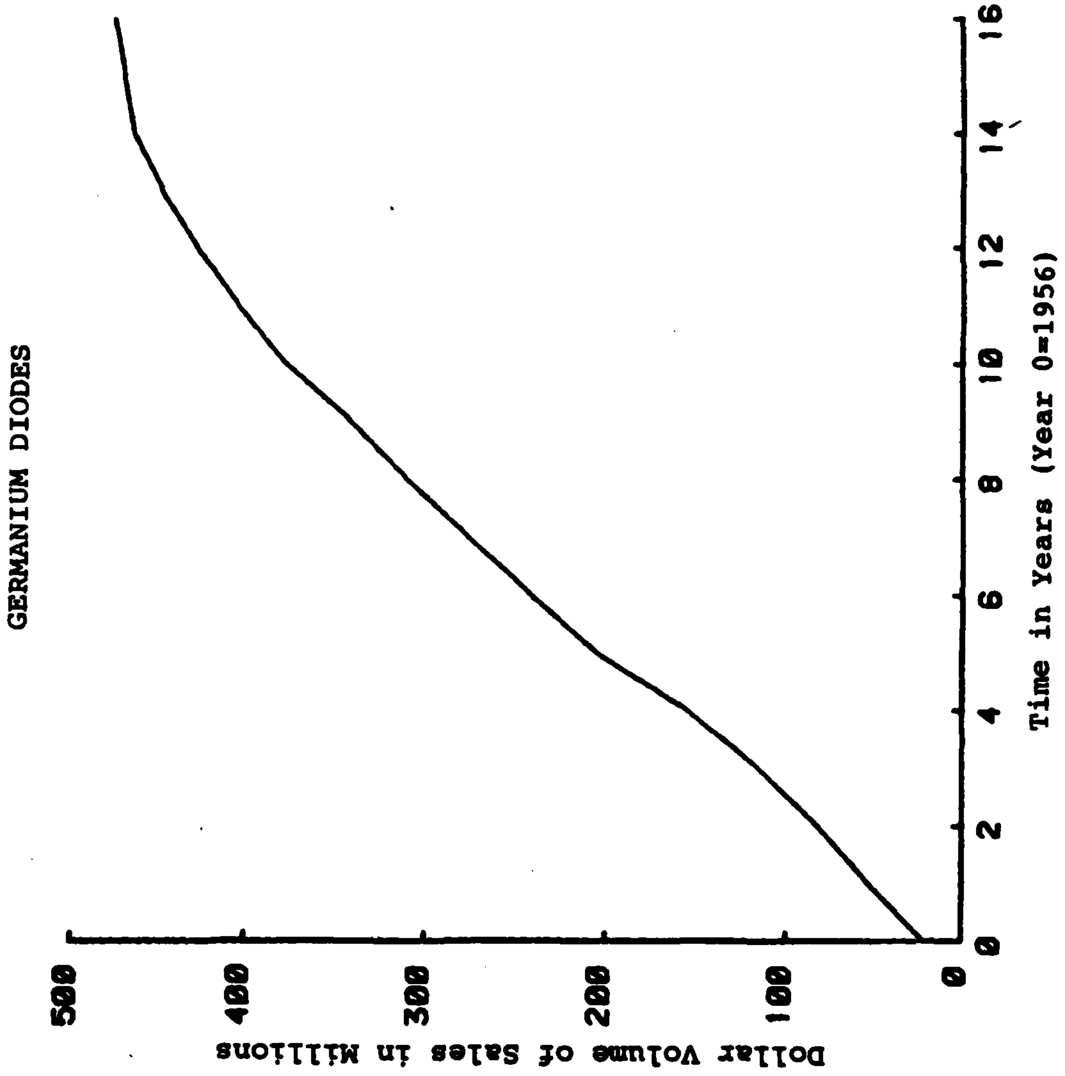


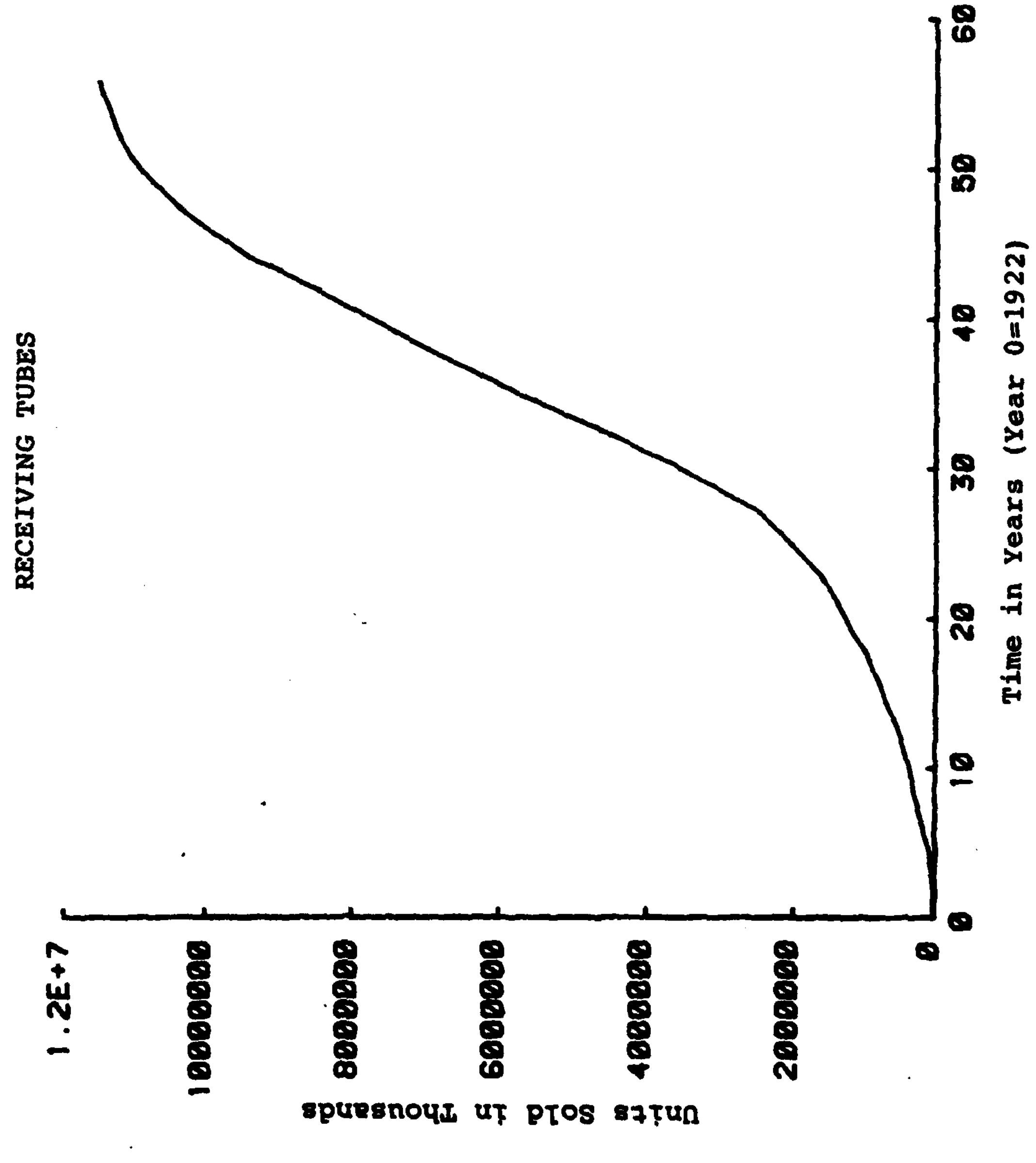
GERMANIUM TRANSISTORS

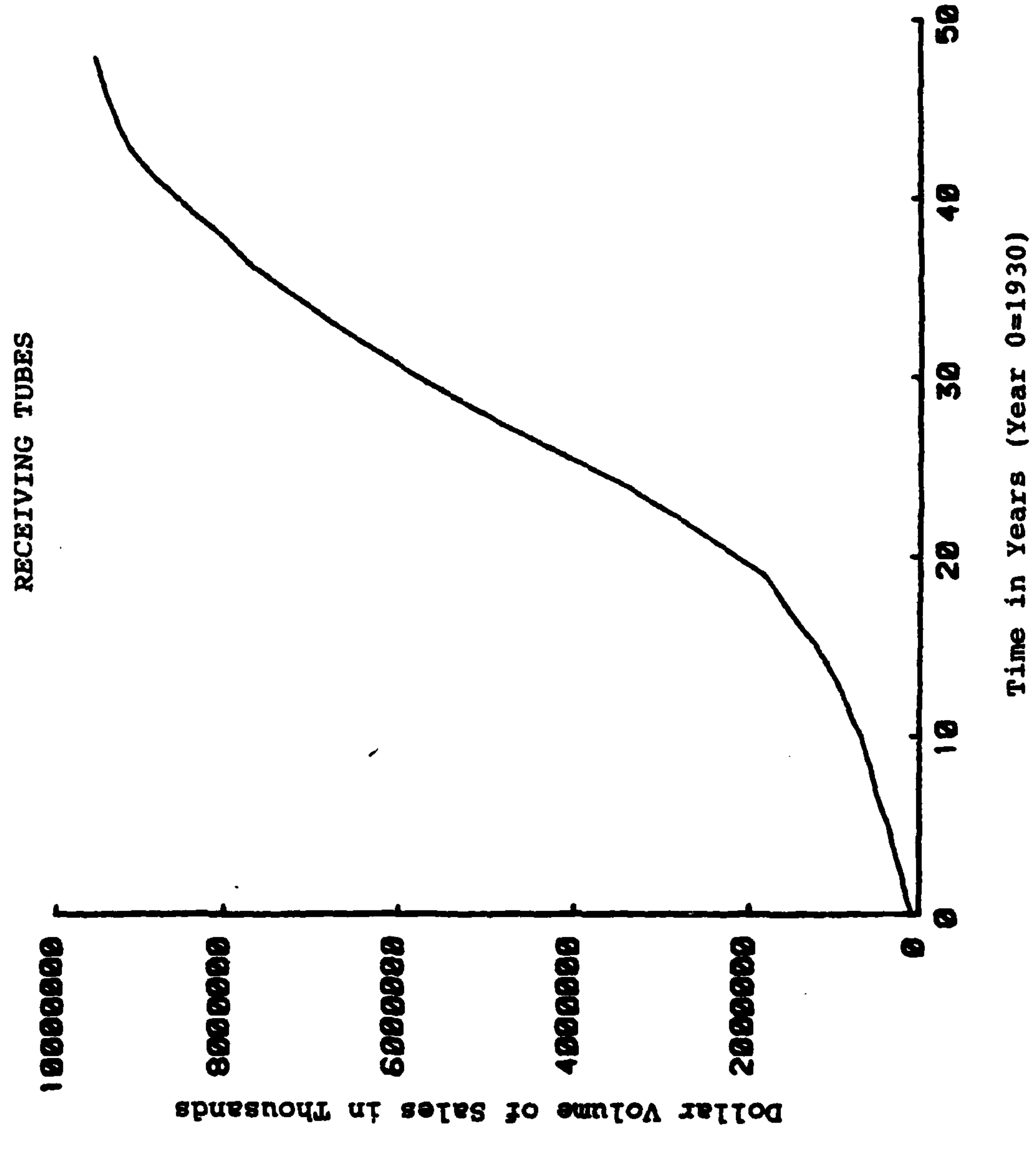


GERMANIUM DIODES




GERMANIUM DIODES
Dollar Volume of Sales in Millions
0
100
200
300
400
500
0
2
4
6
8
10
12
14
16
Time in Years (Year 0=1956)


RECEIVING TUBES
1.2E+7
10000000
8000000
6000000
4000000
2000000
0
Units Sold in Thousands
0
10
20
30
40
50
60
Time in Years (Year 0=1922)


RECEIVING TUBES
Dollar Volume of Sales in Thousands
10000000
8000000
6000000
4000000
2000000
0
0
10
20
30
40
50
Time in Years (Year 0=1930)

APPENDIX H

SAMPLES OF SPSS CONTROL
CARD LISTINGS

```
                                                                        08/03/81
VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.0 -- JUNE 18, 1979


               RUN NAME         HOERL SPECIAL FUNCTION ON RECEIVING TUBE DVS
               PRINT BACK       CONTROL
               VARIABLE LIST    Y,X
               INPUT MEDIUM     CARD
               N OF CASES       49
               INPUT FORMAT     FREEFIELD
               NONLINEAR        VARIABLES=Y WITH X, NB=3/
               MODEL            YHAT=B(1)*(X**B(2))*EXP(B(3)*X)
               PARAMETERS       B(1)=30.901171SB(2)=4.2425B(3)=-0.078633883
               OPTIONS          4
               STATISTICS       7,8,9
               READ INPUT DATA

SPSS RELOADED

          060s5598 CM NEEDED FOR NONLINEAR

          OPTION - 1
          IGNORE MISSING VALUE INDICATORS
          (NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)

          OPTION - 4
          ONLINE PRINT FORMAT
```

```
                                                                    (1
VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.0 -- JUNE 18, 1979


                 RUN NAME         PEARL CURVE ON TRANSISTOR UNIT SALES
                 PRINT BACK       CONTROL
                 VARIABLE LIST    Y,X
                 INPUT MEDIUM     CARD
                 N OF CASES       19
                 INPUT FORMAT     FREEFIELD
                 NONLINEAR        VARIABLES=Y WITH X, NB=3/
                 MODEL            YHAT=B(1)/(1+B(2)*EXP(-B(3)*X))
                 PARAMETERS       B(1)=2900.0SB(2)=273.156713B(3)=0.4827879)
                 OPTIONS          4
                 STATISTICS       7,8,9
                 READ INPUT DATA

SPSS RELOADED

            00054700 CM NEEDED FOR NONLINEAR

            OPTION - 1
            IGNORE MISSING VALUE INDICATORS
            (NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)

            OPTION - 4
            ONLINE PRINT FORMAT
```

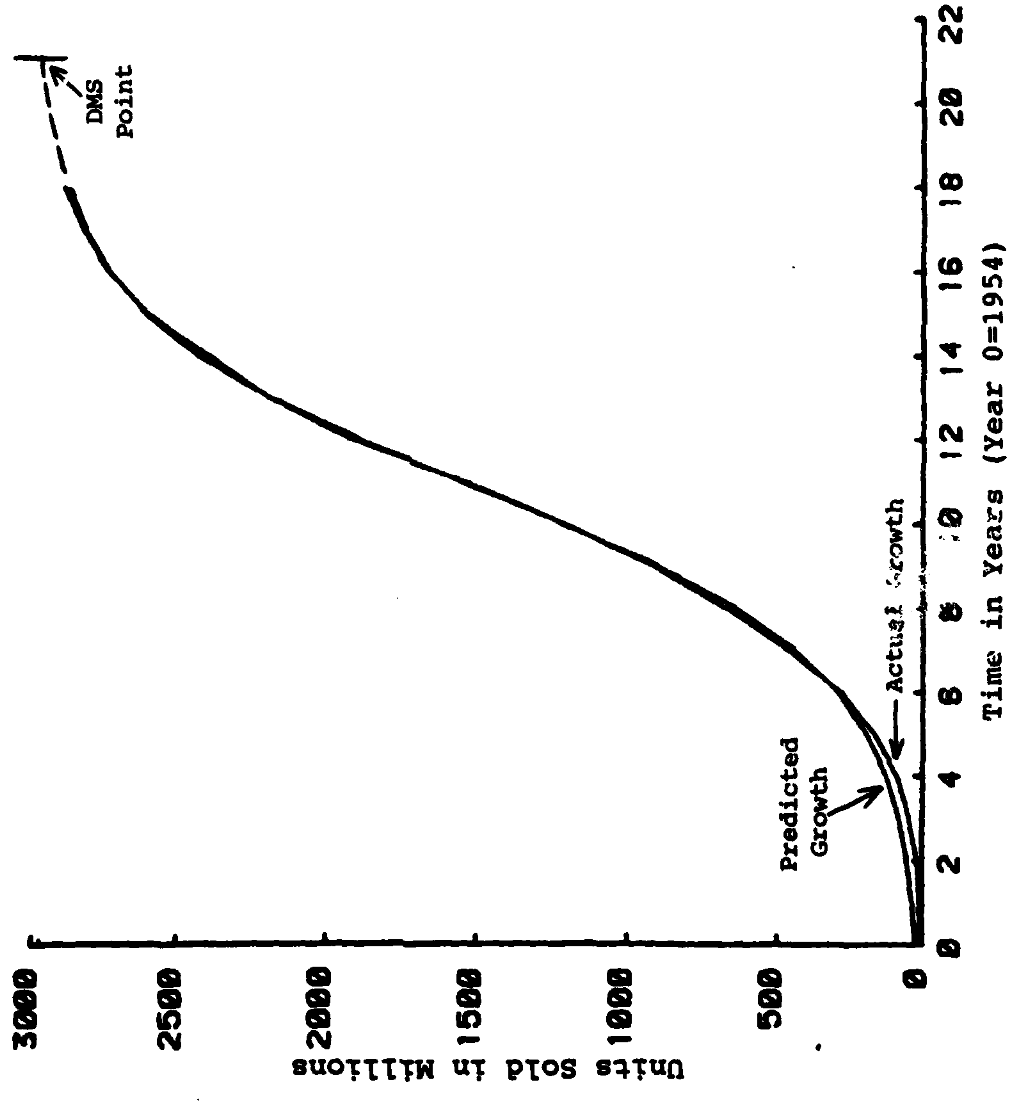
```
                                                               08/03/81
VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.0 -- JUNE 18, 1979


            RUN NAME        POLYNOMIAL REGRESSION ON RECEIVING TUBE DVS
            PRINT BACK      CONTROL
            VARIABLE LIST   VARY,VARX
            INPUT MEDIUM    CARD
            N OF CASES      49
            INPUT FORMAT    FREEFIELD
            COMPUTE         VARX2=VARX*VARX
            COMPUTE         VARX3=VARX2*VARX
            REGRESSION      VARIABLES=VARY,VARX,VARX2,VARX3/
                            REGRESSION=VARY WITH VARX,VARX2,VARX3(4) RESID=0/
            STATISTICS      ALL
            READ INPUT DATA

    00052400 CM NEEDED FOR REGRESSION


    OPTION - 1
    IGNORE MISSING VALUE INDICATORS
    (NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)
```

APPENDIX I

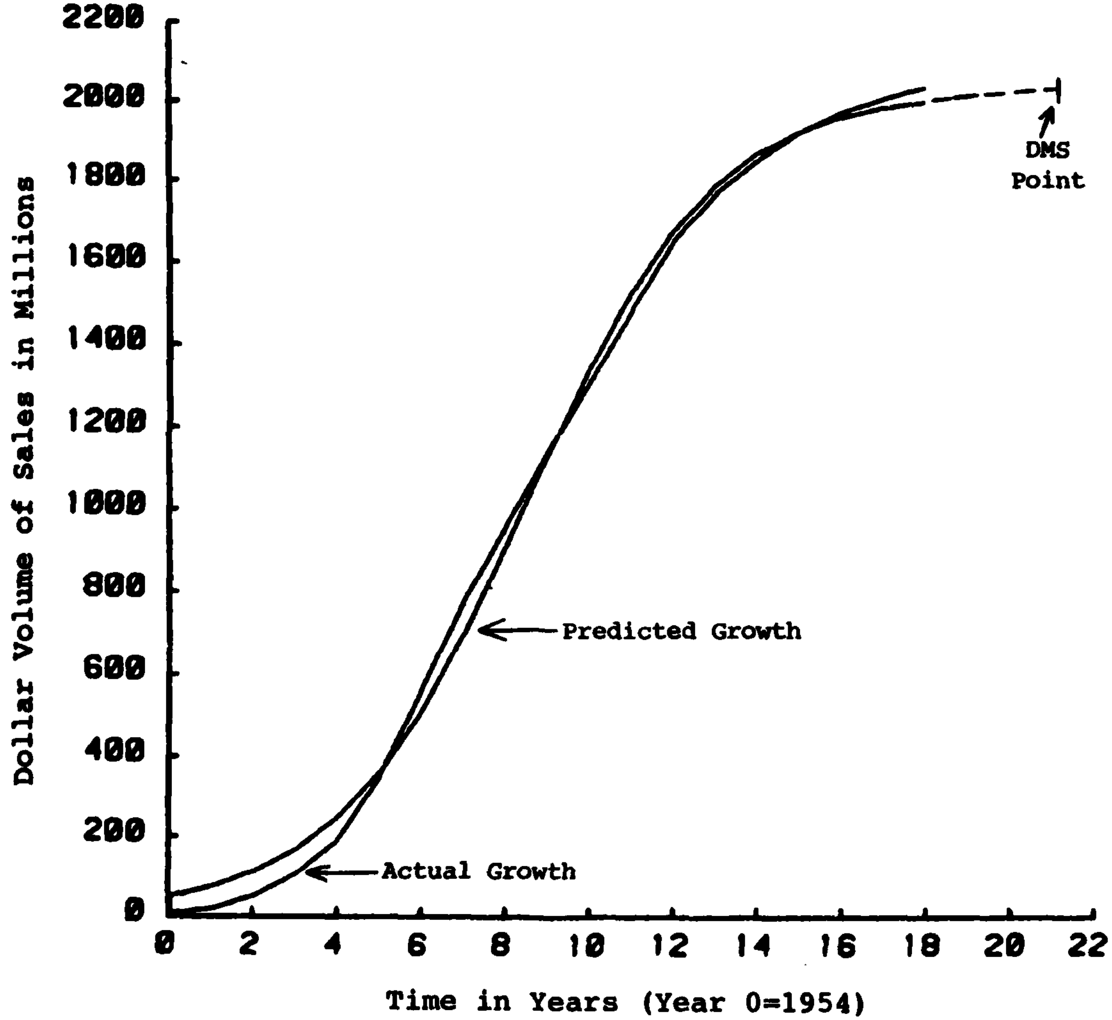
PREDICTED AND ACTUAL GROWTH CURVES[4]

[4]The Pearl function ($y = L/(1 + ae^{-bx})$) computed the predicted growth curves.

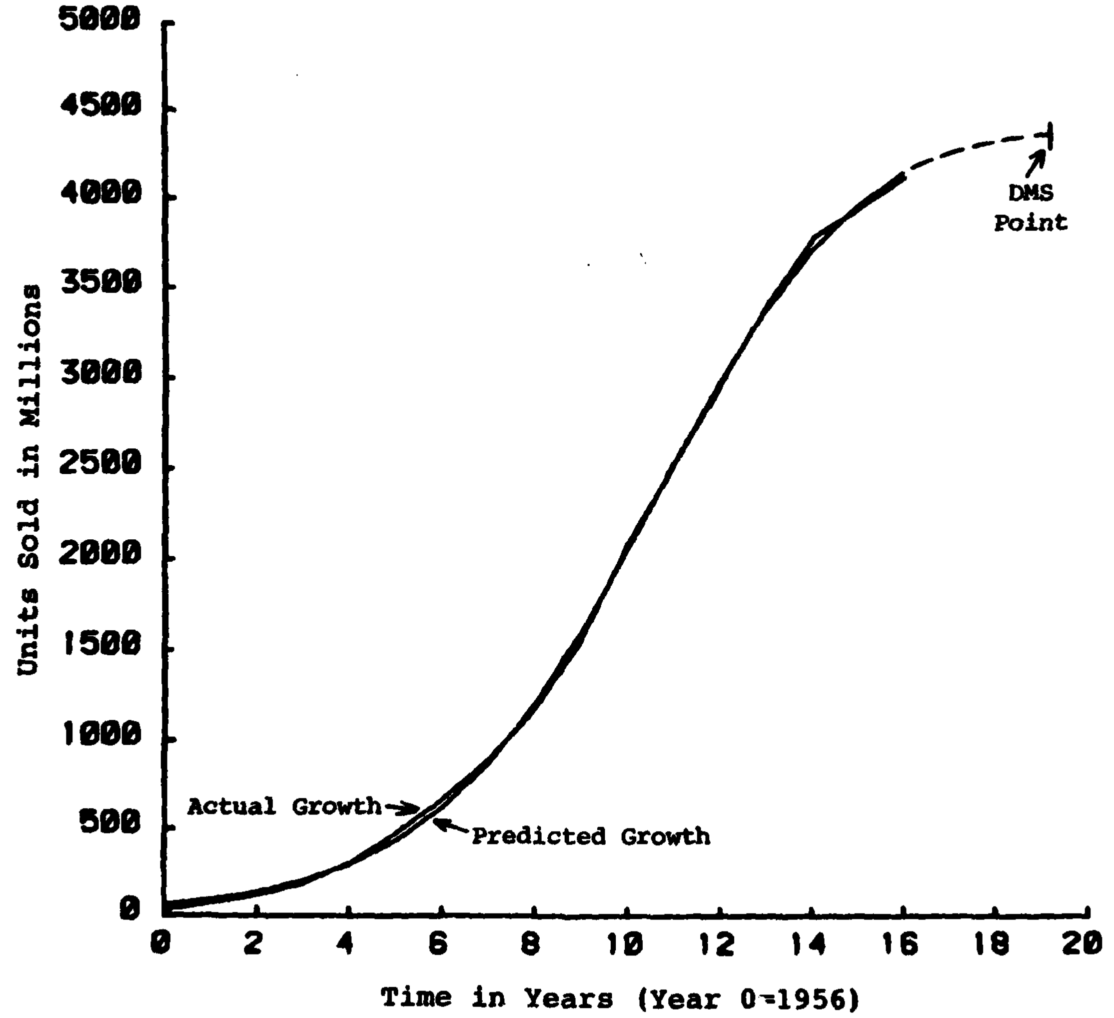
GERMANIUM TRANSISTORS

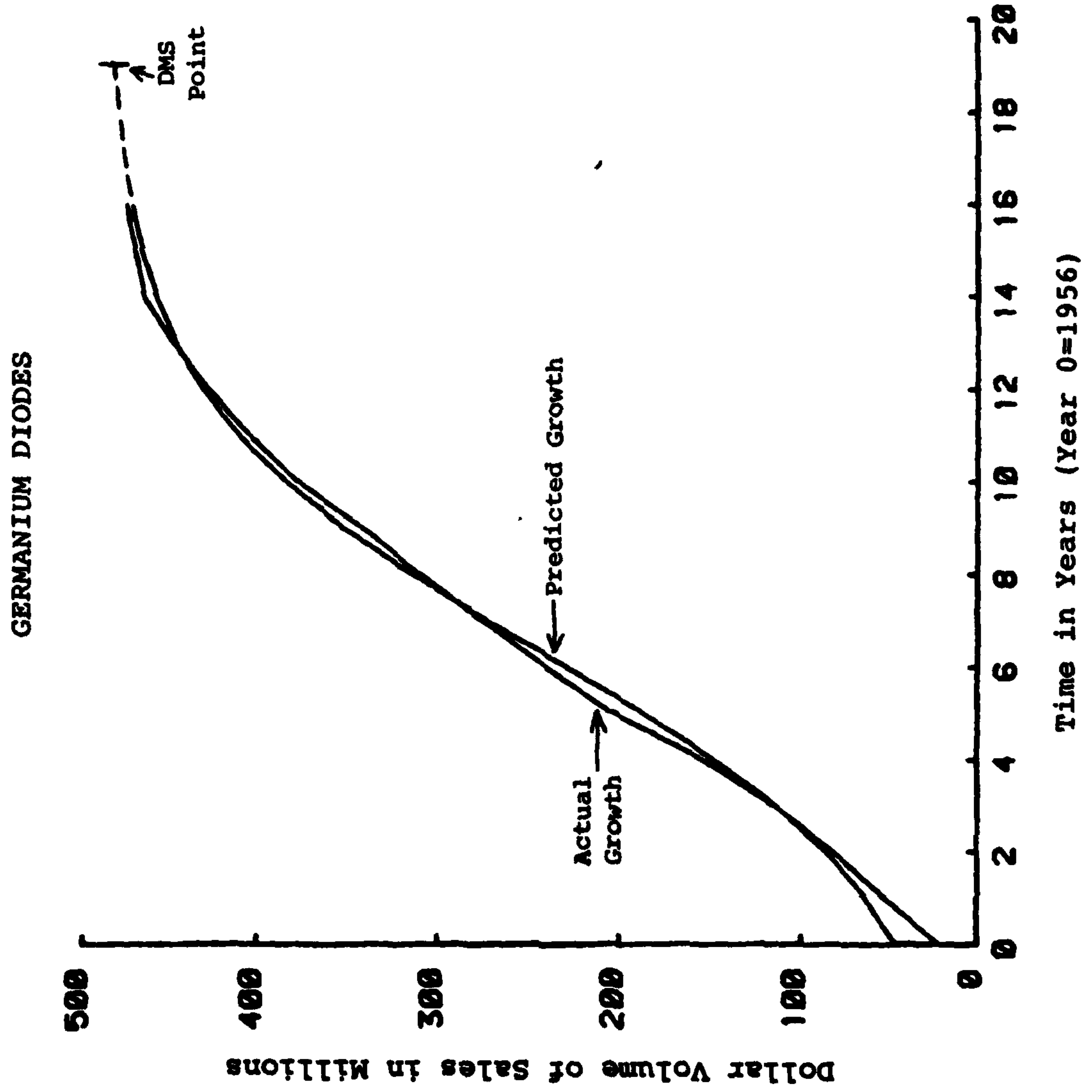


GERMANIUM TRANSISTORS

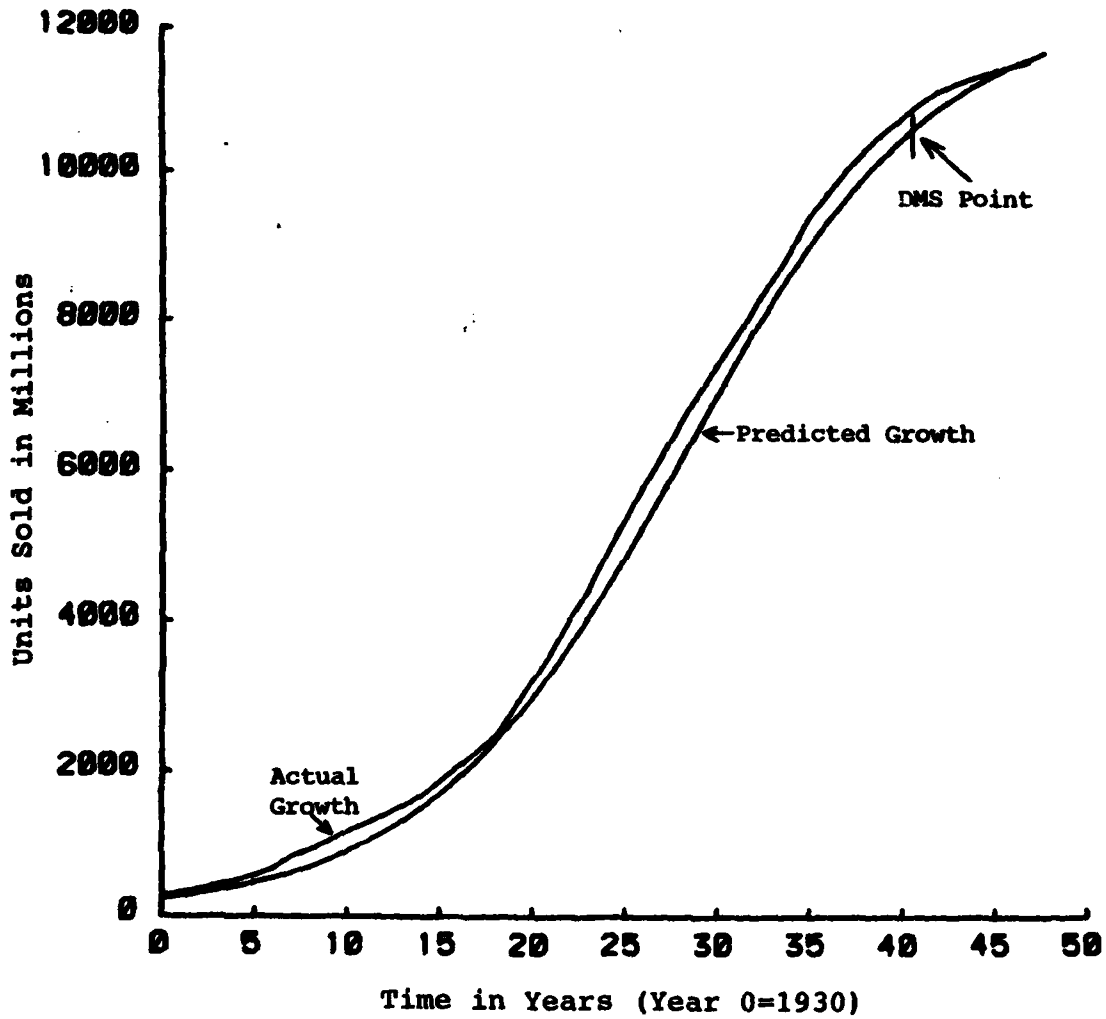


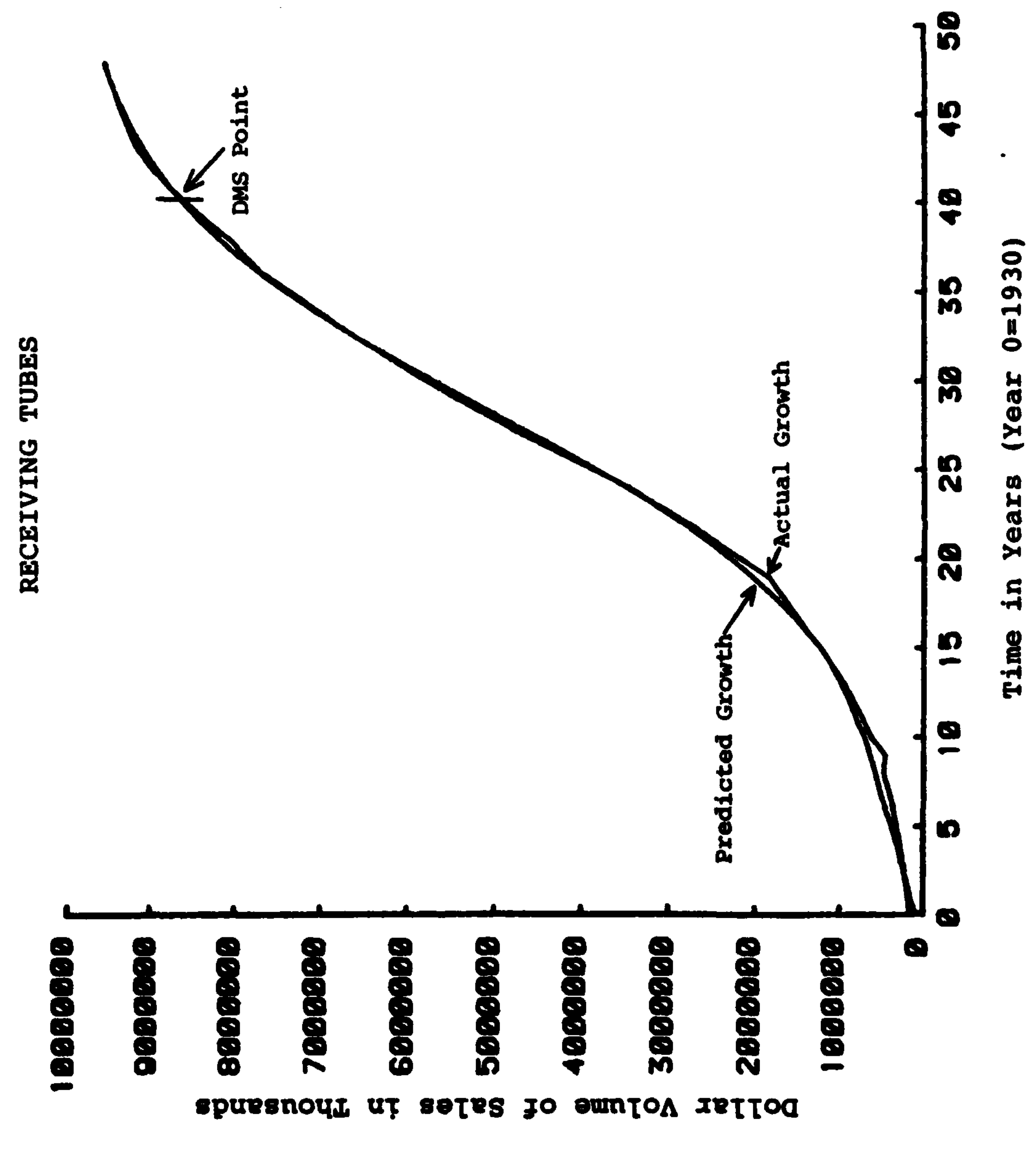
GERMANIUM DIODES




GERMANIUM DIODES
DMS Point
Predicted Growth
Actual Growth
Dollar Volume of Sales in Millions
0
100
200
300
400
500
Time in Years (Year 0=1956)
0
2
4
6
8
10
12
14
16
18
20

RECEIVING TUBES




RECEIVING TUBES
DMS Point
Actual Growth
Predicted Growth
Dollar Volume of Sales in Thousands
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
5
10
15
20
25
30
35
40
45
50
Time in Years (Year 0=1930)

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